This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

LANE MEDICAL LIBRARY STANFORD
D316 .S63 1918 STOR
A text-book of biology for students in g
24503385755

LANE

MEDICAL LIBRARY

SEAL OF THE LELAND STANFORD JUNIOR UNIVERSITY
1885

LEVI COOPER LANE FUND

A TEXT-BOOK
OF
BIOLOGY

FOR STUDENTS IN GENERAL, MEDICAL AND TECHNICAL COURSES

BY

WILLIAM MARTIN SMALLWOOD, PH.D. (HARVAR
PROFESSOR OF COMPARATIVE ANATOMY IN THE LIBERAL ARTS COLLEGE OF
SYRACUSE UNIVERSITY

THIRD EDITION, ENLARGED AND THOROUGHLY REVISED

ILLUSTRATED WITH 235 ENGRAVINGS AND 8 PLATES
IN COLORS AND MONOCHROME

LEA & FEBIGER
PHILADELPHIA AND NEW YORK
1918

Copyright
LEA & FEBIGER
1918

D316
S63
1918

THIS EDITION IS DEDICATED

TO

PROFESSOR CHARLES WESLEY HARGITT

WHO HAS BEEN

PROFESSOR OF ZOÖLOGY AND DIRECTOR

OF THE

ZOÖLOGICAL LABORATORIES OF SYRACUSE UNIVERSITY

SINCE 1891

46422

PREFACE.

In this edition the general plan of the previous editions is retained but made more logical by bringing forward the chapters on plants so that the value to be derived from the evolutionary point of view can be employed in the study of the plant types discussed. The chapter on hydra is shifted for a similar reason.

The section dealing with the biology of cells (Chapters VIII–XI) has been entirely rearranged and extended in order that it may furnish a better foundation for the present-day conception of biology.

The laboratory suggestions at the beginning of each chapter are omitted and attention is called to "Laboratory Outlines" by Hargitt and Hargitt which meets the needs of those wishing laboratory directions for the present edition. This book may be secured by writing directly to Professor C. W. Hargitt, Syracuse University, Syracuse, N. Y.

The historical development of biology, typified in large part by the emphasis which certain great men placed first upon one aspect of living things and then upon another, affords a natural approach to our subject: Linnaeus (1707–1778) emphasized the external form of organisms, while Haller (1708–1777) inquired into the general physiological activities of living things. These two men may be given credit for defining the two lines of study, morphology and physiology, which enter so largely into all modern courses in biology.

Cuvier (1789–1832) gave to the morphological study of organs a greater importance than his predecessors, and Müller (1801–1858) a little later threw into prominence the function of organs. Next the organs were found to be made up of tissues, and Bichat (1771–1801) gave particular attention to their composition and work. All of the investigations up to this time had failed in part because the ultimate structure of the organism was unknown.

With the discoveries of Schleiden and Schwann (1836–1840), that all living things can be analyzed into cells, a morphological basis for biological study was established. The name of Virchow (1821–1903) may properly be linked with the physiological study of cells. Dujardin (1801–1860) gave a great deal of attention to protoplasm, and Bernard (1813–1878) emphasized the importance of protoplasm in analyzing physiological activities.

Biology has come through a series of historical steps to the present-day point of view which aims to interpret biological problems in terms of protoplasm. It also has a pedagogical value which is lacking when a course in biology begins with cells, for in this plan of study, the student continually passes from what he knows to what is new. But relatively few organisms are composed of single cells—nearly all living things are complex. We have to deal with organisms as they exist today and this is the chief problem which the student in a beginner's course has to meet.

In the study of the frog we have an organism that is large enough to be easily seen and handled. It is analyzed in terms of its relation to other animals, in terms of its organ systems, in terms of its food, and in terms of its method of reproduction. In each instance the analysis continues until the biological unit, the cell, is reached.

After the student has thus been introduced to the biological method of study, it is easy to examine some unicellular organisms (Chapters VIII–XI). In this study of the life of the unicellular organism the student soon discovers that the essential life-characteristics of the frog are all present in these microscopic animals and plants. These are biological facts of large importance. A substantial although inadequate foundation has now been laid for the important question, What is life?

With these fundamental questions presented, a certain amount of variation and latitude is to be expected in the sequence and content of the remainder of the course.

It is the conviction of the writer that the student should first be given an opportunity to study the actual animals and plants before the principles of structure, activity, etc., are taken up. Such a method furnishes him with a few concrete facts which he has secured himself. This tends to make the laboratory work the important part of the course as it should be. The subject matter of this book is, therefore, mostly written on the assumption that the student has already acquired some first-hand information in the laboratory.

I am under obligation to Professor Loren C. Petry for writing Chapter IX, to Miss Elizabeth Clark who has made under my direction practically all of the original drawings, and to my wife for reading the entire proof.

W. M. S.

Syracuse, N. Y., 1918.

CONTENTS.

THE FROG AS A TYPE OF COMPLEX ANIMALS.

CHAPTER I.

ORGANISM.

Movement 17
Organism Defined 18
Amphibia 20

CHAPTER II.

ORGAN SYSTEMS—SCOPE OF BIOLOGY.

Digestive Canal 26
Digestive Glands 27
Respiratory Organs 29
Urinogenital Organs 30
Cœlom 33
Organ Systems 33
Scope of Biology 33

CHAPTER III.

PHYSIOLOGY OF DIGESTION IN THE FROG.

Need of Food 35
Proteins 36
Carbohydrates 37
Fats 37
Digestion 38

CHAPTER IV.

CIRCULATION—METABOLISM.

Heart 41
Blood 43
Respiration 44
Metabolism 46
Metabolic Water 49

CHAPTER V.

Tissues and Cells of the Frog.

Histology 51
Histology of Intestine or Stomach 51
Tissues 52
  Epithelial 52
  Connective 53
  Muscular 54
  Nervous 55
The Cell 55
Cell Theory 56
Protoplasm 57

CHAPTER VI.

Nervous System of the Frog.

Nervous System 58
Tissues of the Central Nervous System 62
Neurón 62
Origin of the Axon 64
Histology of the Spinal Cord 64
Nerves 65
Stimulation of Nerves 66
Organic Movement 66

CHAPTER VII.

Embryology.

Somatic and Germ Cells 68
Ova and Sperm Cells 70
Maturation 73
Fertilization 78
Segmentation 79
Tadpole 81
Life Cycle 84

BIOLOGY OF UNICELLULAR ORGANISMS.

CHAPTER VIII.

Paramecium—An Animal Made Up of a Single Cell.

Habitat 85
Appearance 85
Structure 86
Physiology 90
Locomotion 90
Food 91
Digestion 91

Excretion 92
Respiration 92
Metabolism 92
Reproduction 92
Conjugation 92
Organic Movement 93
Kinds of Paramecia 95
Protozoa 95
Protozoön Animals 96
Biology of Cells 96

CHAPTER IX.

PLEUROCOCCUS—A PLANT CONSISTING OF A SINGLE CELL.

Habitat 97
Morphology 97
Photosynthesis 99
Other Materials and Syntheses 102
Metabolism 103
Reproduction 103
Other Unicellular Green Plants 104

CHAPTER X.

BIOLOGY OF BACTERIA AND YEAST. THE SIMPLEST LIVING ORGANISMS.

Organized Ferments 105
Yeast 105
    Morphology 105
    Reproduction 106
    Food 107
    Metabolism 107
Bacteria 108
    Relationships 108
    Morphology 108
    Size 108
    Structure 110
    Motility 110
    Reproduction 110
    Zoöglea 111
    Metabolism 111
    Enzymes and Toxins 112
    Fermentation 112

CHAPTER XI.

WHAT IS LIFE?

Spontaneous Generation 114
Chemical Composition of Living Matter 115
The Physical Properties of Protoplasm 118
    Fibrillar Theory 118
    The Alveolar Theory of Bütschli 118

The Biological Properties of Protoplasm 119
  Relation to Life to the Living Body 119
  Size of Living Bodies 121
  Age of Living Bodies 121
  The Cell and Living Protoplasm 121
  Reproduction and Life 121
  Growth and Life 122
  The Awareness of Living Protoplasm 122
  Maintenance of Life 123
The Fate of Dead Organisms 123

CHAPTER XII.

SOME LOWER PLANT TYPES.

Thallophytes 125
Chlorophyceæ, the Green Algæ 126
  Spirogyra 126
  Vaucheria 127
Phycomycetes, the Algæ Fungi 129
  The Bread Mould 130
  Water Moulds 132
  Bryophytes 132
  Pteridophytes 133
  Spermatophytes 134
  The Seed 135

CHAPTER XIII.

AN ANGIOSPERM—TRILLIUM GRANDIFLORUM.

Trilliums 135–145

CHAPTER XIV.

CLASSIFICATION AND THE ORIGIN OF MULTICELLULAR ORGANISMS.

Classification 146
  Intermediate Type 148
  Blood Relationships 152

CHAPTER XV.

HYDRA—AN ANIMAL MADE UP OF TISSUES ONLY.

Kinds 153
Morphology 153
Food 153
Structure 154
Nematocysts 156
Reproduction 156
  Asexual Method 156
  Sexual Method 159
Regeneration 160
Physiology 160
Winter Life of Hydra 165

CHAPTER XVI.

THE "WORM" GROUP—THE EARTHWORM AS A TYPE.

External Morphology 166
Habits and Special Senses 166
Organ Systems 167
Reproduction 168
Regeneration 170
Histology 170

CHAPTER XVII.

MOLLUSCA.

General Characters 173
Food of Clams and Oysters 175

CHAPTER XVIII.

THE CRAYFISH.

Kinds and Distribution 177
Food 177
General Characteristics 177
Modified Somites 178
Exoskeleton 178
Jointed Feet 179
Organ Systems 181

CHAPTER XIX.

INSECTS.

Number 187
General Characters 187
The Honey Bee 187
    Kinds 188
    The Honey Bee Colony 188
    The Queen 188
    Drones 189
    Workers 189
    Structure of the Honey Bee 189
        Respiration 190
        Reproduction 190
Honey 192
Pollen Collecting 193

CHAPTER XX.

SOME BIOLOGICAL ADAPTATIONS.

Adaptation 198
Parasitism 200
Classification of Parasites 201
Extent of Parasitism 202

Parasitic Habits 203
White-pine Blister Rust 206
Why Are Parasites Sometimes Very Numerous? 208
Symbiosis 209
Community Life 211
Gregariousness 211

CHAPTER XXI.

SOME BIOLOGICAL FACTORS IN DISEASE.

The Role of Biology 213
Rattlesnakes 214
Amanita 216
Sporotrichosis 217
Crown Gall 218
Malaria 220
The Bacterial Diseases 222
The Filterable Viruses 224
Tapeworms, Hookworms, and Others 224
Animal Tumors 226
Disease Carriers 227
The Prevention of Disease 229
Immunity 230
Protection and Adaptation 233

CHAPTER XXII.

EVOLUTION.

Evolution 239
Some Evidences of Organic Evolution 241
    Fundamental Characteristics of Living Things 241
    Embryology 241
    Homology 245
    Palæontology 247
Philosophy of Organic Evolution 248

CHAPTER XXIII.

VARIATION—HEREDITY.

Variation 256
    Definition 256
    Variation in Paramecia 256
    Variation in Earthworms 257
    Variation in Crayfish 258
    Variation in Insects 260
    Variation in Ranunculus 261
    Methods of Studying Variation 261
Heredity 262
Heredity and the Cell 263
Mendelism 267
Heredity and Man 277
The Kallikak Family 277
Eugenics 279

CHAPTER XXIV.

Animal Behavior and Its Relation to Mind.

Animal Behavior 281
Some Biological Aspects of the Human Mind 282
Sense Organs 286
Some Types of Animal Behavior 288
    Ameba 289
    Gonionemus 290
    Earthworms 290
    Wasp 292
    Habit Formation in Frogs 292
    Raccoons 293
Significance of Animal Behavior 293
    The Psychology of One-celled Organisms 294
    The Psychology of Simple Multicellular Animals 294
    The Psychology of the Insect Group 294
    The Psychology of the Lower Vertebrate Animals 295
    The Psychology of the Higher Vertebrates 295
    The Psychology of the Primates 296
Appendix 299
    Classification of Animals and Plants 299

THE FROG AS A TYPE OF COMPLEX ANIMALS.

CHAPTER I.

ORGANISM.

Movement.—The steam engine, the printing press, or gliding aëroplane never fail to excite our admiration. The complicated machinery operates on almost frictionless bearings in accomplishing marvellous results, but none of these wonderful products of the inventive skill of many minds equals the frog when considered simply as a machine. Jumping and swimming involve a series of movements that are much more complicated than simply straightening out the limbs. Each limb takes a definite direction, one that is selected, and this alone places the movement of a limb as superior to the most perfect machine. In order that there may be selection in the direction of the movement of a limb, there must exist muscles capable of causing the limb to go in a given direction; but muscles need something to which they can be attached in order to make these selected movements. Such a framework is furnished by the bones. Bones and muscles alone are not capable of producing a given result. There must be a directing agent, something responsible for the movement and the selection. This is the work of the central nervous system and of the nerves that end in each muscle. The frog thus analyzed is easily seen to be more complicated than any machine. One of the reasons why the term living is given to the frog is because it can make these selective movements of the limbs. For the name frog may be substituted the name of any other thing that has biologically, not humanly speaking, this same property of exercising choice in its movements and the term living can be applied to it.

There is movement in a variety of things in Nature. A familiar example is that of the wind. While the usual paths of the wind are known and charted, and it has been determined that the cause of the wind lies largely in differences in temperature and barometric pressure, yet there is nothing here that is comparable to the selected direction of movement in a living animal. Gunpowder and the various explosives have each a characteristic movement, but they all remain in a static condition unless acted upon by some outside stimulus, as the lighted fuse, and then their movement is of one kind. Movement considered from a physical or chemical stand-point is of the same nature whether in inanimate or animate Nature; but there is always in animate movements the additional regulative factor which permits movement to be regarded as one of the fundamental properties of living matter though there are seasons or periods in the life of many animals when movements cease and the animal becomes quiescent.

FIG. 1.—*Rana clamitans.* ♀.

The four legs of the frog move in such a manner as to produce a given result, the two eyes reveal the same picture, the complicated changes in breathing result in drawing air into the lungs and allowing it to escape, and many other equally difficult changes are taking place continually. Anything which can produce these peculiar changes is alive and is called an organism.

Organism Defined.—The term organism is given to any particle of living substance capable of independently sustaining itself. "*An organic individual is a unitary mass of living substance which under definite vital conditions is capable of self preservation.*" This definition is so formulated as to include every condition under which living things have come to live, the minute bacteria or the large elephant, the simple worm or the group of individuals in the ant community.

These definitions include all forms of living things but because

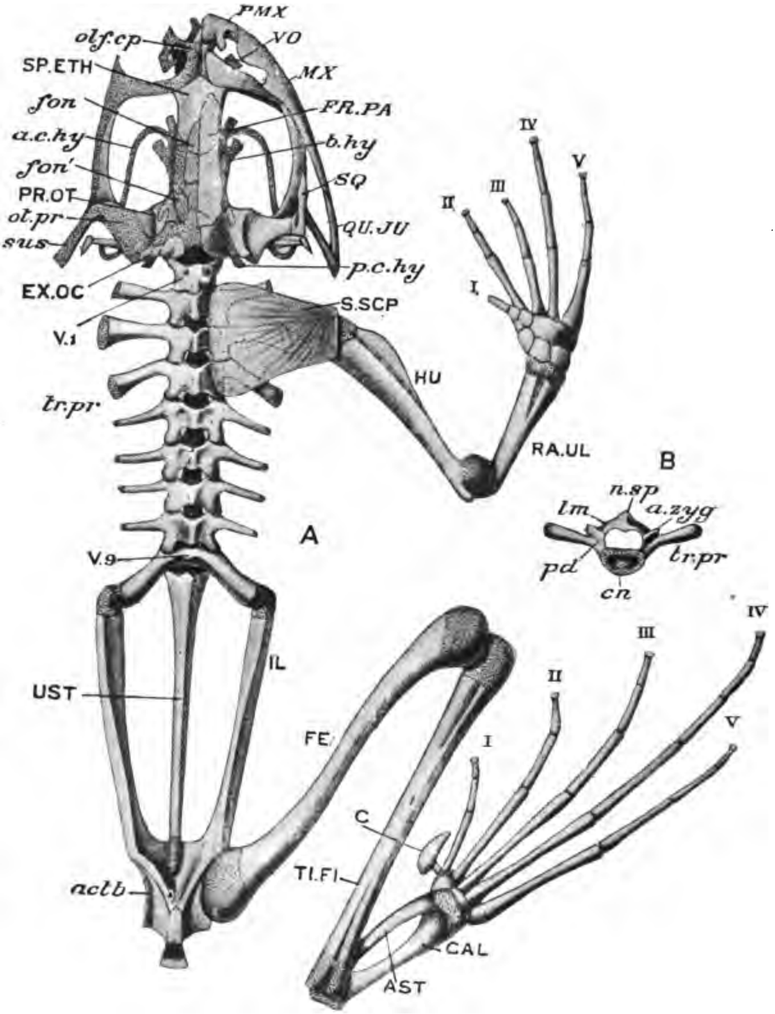


FIG. 2.—*Rana temporarai.* *A*, the skeleton from the dorsal aspect; the left half of the shoulder girdle and the left fore and hind limbs are removed, as also are the membrane bones on the left side of the skull. Cartilage parts dotted *a.c.hy*, anterior cornu of hyoid; *actb*, acetabulum; *AST*, astragalus; *b.hy*, basihyal; *C*, calcar; *CAL*, calcaneum; *EX.OC*, exoccipital; *FE*, femur; *fon*, *fon'*, fontanelles; *FR.PA*, fronto-parietal; *HU*, humerus; *IL*, ilium; *MX*, maxilla; *olf.cp*, olfactory capsule; *ot.pr*, otic process; *p.c.hy*, posterior cornu of hyoid; *PMX*, premaxilla; *PR.OT*, proötic; *RA.UL*, radioulna; *SP.ETH.*, sphenoethmoid; *SQ*, squamosal; *S.SCP.*, suprascapula; *sus*, suspensorium; *TI.FI*, tibiofibula; *tr.pr*, transverse process; *UST*, urostyle; *V*.1, cervical vertebra; *V*.9, sacral vertebra; *VO*, vomer; *I-V*, digits; *B*, the fourth vertebra, anterior face; *a.zyg*, anterior zygapophysis; *cn*, centrum; *lm*, lamina; *n.sp*, neural spine; *pd*, pedicle; *tr.pr*, transverse process. (After Howes, slightly altered, from Parker and Haswell.)

many of them are so simple the following "An organism is composed of organs" does not apply, although it describes and defines correctly the frog as it does all large animals, and is the most used and familiar definition. Whenever this latter definition can be used, the animal is complex, consisting of many highly specialized parts, as arms, legs, eyes, ears, taste and touch organs, etc. Each of these has a given work to do and is called an organ. Only a few of the organs in the frog have been observed as yet in this course but others will be worked out later. *An organ is a structure which does a given work for the organism and is itself composed of many distinct parts.*

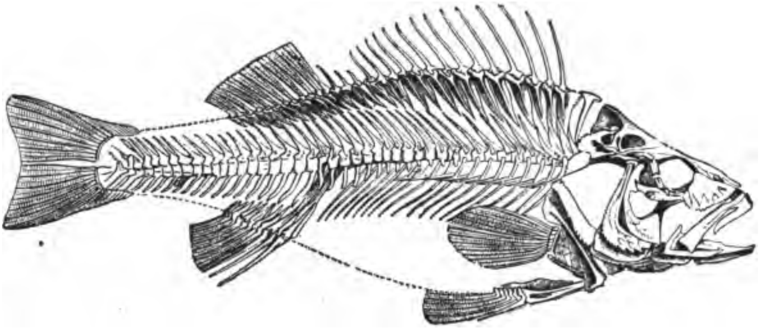


FIG. 3.—Skeleton of a fish. (Kny-Scheerer Co.)

Amphibia.—A long time ago when men first became interested in animals they arranged them into certain groups, because all of the members of the group possessed certain structures in common. The head and trunk of the frog at once suggest that it belongs to a higher group of animals than the earthworm or crayfish. The internal skeleton shows that there are a number of separate bones joined together in the back to form what is termed the vertebral column. The presence of these serially arranged bones at once places the frog in the general class, *vertebrata,* and an examination of Figs. 2 to 6 shows how closely the frog is related to these other vertebrates. There are a number of animals that have frog-like skeletons, a soft, moist, naked skin, pentadactyl appendages, and frog-like habits, which are arranged under the general subclass of *Amphibia* which is one of the five great groups of vertebrates. Each of these large groups of vertebrates is subdivided into many genera, families, etc., and one finally comes to the frog family technically termed the Ranidæ (see Table of Classification at end of text). In the Ranidæ family the single genus of Rana is found in North America. This large genus of about 140 species furnished but fourteen of them to our continent, of which the following are best known: *Rana pipiens, R. catesbiana, R. clamitans, R. palustris, R. sylvatica.*

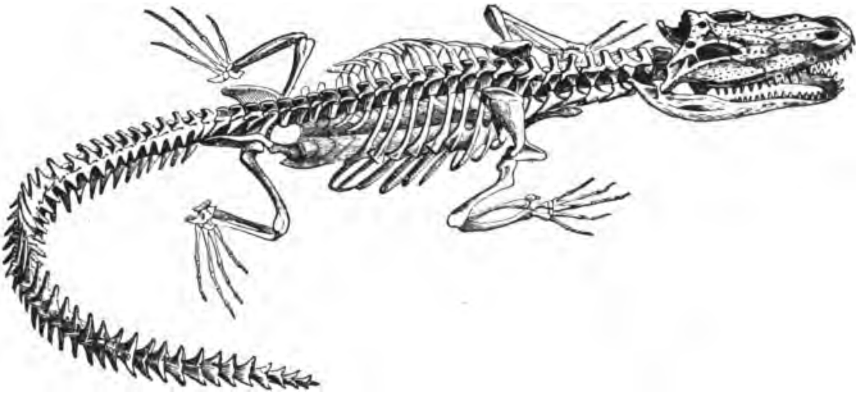


Fig. 4.—Skeleton of an alligator. (Kny-Scheerer Co.)

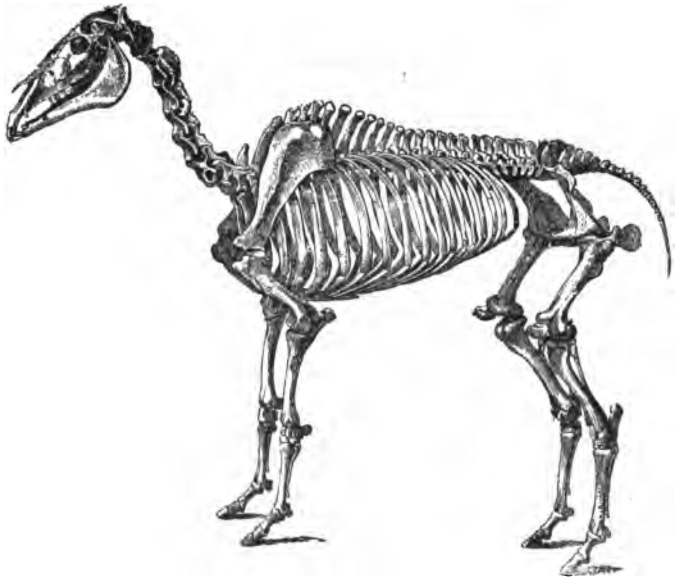


Fig. 5.—Skeleton of a horse. (Kny-Scheerer Co.)

Habits.—The general habits of the group will be illustrated by describing *R. catesbiana*. The frogs collected for laboratory study in New York State are the leopard frog (*Rana pipiens*) and the large green frog (*Rana clamitans*). The Amphibia are all aquatic for a part of the time and but few of them (toads) remain away from the water for any length of time.

Rana catesbiana is the largest of the North American frogs and is commonly found with a body six to eight inches long when adult. The following technical description illustrates how a taxonomist described a given species of frog. You should make a similar study in the laboratory. In color the body is green or greenish-brown. The back and sides may be plain in color or may be darkly spotted. Spots distinct or connected. Arms and legs spotted or barred with dark. Under parts white, distinctly or obscurely spotted and mottled with dark color. Throat of male may be yellow. Iris of eye is either golden or reddish bronze. The femur is about equal in length to the tibia. Head broad and flat; body stout and flat; ear of male larger than eye; ear of female about the size of the eye. Toes broadly webbed, no joints free, except the last of the fourth toe. Hind leg 7 to 10 inches long. Such a description illustrates the first stage in the development of biology, the morphological period of Linnaeus.

FIG. 6.—Skeleton of a seal. (Kny-Scheerer Co.)

This species of frog grows to a large size and may be found commonly with a body six inches long, although often secured much larger. They are quite abundant in many of the Adirondack ponds and streams. In fact where they are abundant, the other frogs are absent, probably because being smaller, they are eaten by them. The bull frogs are usually found sitting partly buried in the soft mud or concealed by sticks or grass; when disturbed they dive to the bottom and stir up the mud; then swim back to the edge of the water usually a foot or two from where they jumped. This habit and the color of their skin is their chief protection from snakes, mud turtles, fish, birds, etc.; they are defenseless unless thus concealed. Wright says that *R. catesbiana* is found along both upland and lowland streams, in clear brooks which feed cold, nearly sphagnous ponds, and also along water-courses laden with such marshy vegetation as lizard-rail, marsh-cress arrowhead, pickerelweed, and swamp-loosestrife.

FIG. 7.—Linnaeus at sixty years, 1707–1778. (From Locy's Biology and Its Makers.)

Carl von Linné or Linnaeus, introduced the method of naming plants and animals that is used at present and is the founder of the modern methods of classification. He confined his studies chiefly to such descriptions of living things as are illustrated in the text by Rana catesbiana. He represents the beginning of the scientific study of biology which was concerned with the general external appearances of organisms and which is known now as the science of taxonomy.

It is easy to catch them by dangling a hook variously baited in front of their noses. When this is moved slightly, it is usually jumped at, although it may be held still against the nose for some time and be declined. Their food is selected from insects, worms, decaying meat, tadpoles and small frogs. The front leg is used in pushing large objects into the mouth. All food is swallowed at once. The tongue is the chief organ used in securing small animals. It is thrown out and the passing insect is captured by the sticky secretion on its surface.

The evening croaking of frogs, especially *Rana clamitans*, suggests that there is a sound-producing organ, and such is the case, for the sound results from forcing air past vocal cords. This voice of the bull frog is a sonorous bass with a good carrying power. "Blood 'n' ounds," "be drowned," "jug-o-rum" are some of the expressions which are used to imitate the sound. The croaking begins about three weeks after the frog emerges from hibernation. Vocal sacs in the side of the neck of the male act as resonators but are not capable of producing any sounds themselves. By holding a frog under water and gently rubbing it, croaking can be produced. The air comes out into the mouth and is then returned to the lungs as if it were just being breathed into the mouth, the air is thus used over and over in sound production.

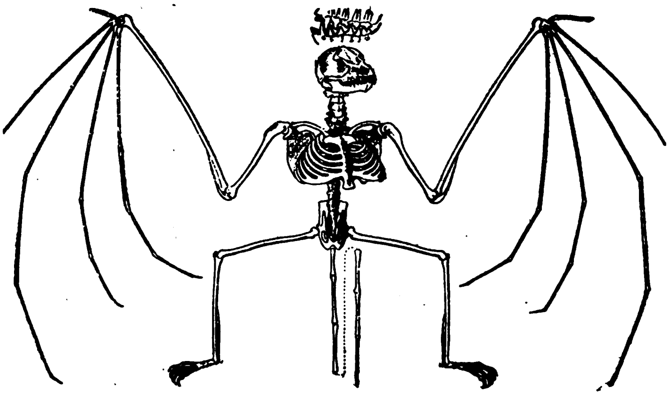


Fig. 8.—Skeleton of a bat. (Kny-Scheerer Co.)

The activities of the frog are largely regulated by the seasons. Its body temperature is about that of the surrounding medium in which it lives, it therefore varies from season to season. The term cold-blooded is applied to fish, amphibia, and reptiles because of their low and varying bodily temperature. During the winter the frog hibernates in the mud below the frost line. The vital activities are greatly lessened, the lungs emptied (cutaneous respiration sufficing), mouth closed, the heart beats feebly and slowly. The energy required to sustain this lowered vitality is taken in part from the muscles and accumulated fat. *R. catesbiana* is the last of the frogs to come out of hibernation. As soon as the water averages about 64° F. and the air 68° to 75° F., one may expect to find them appearing after their winter sleep. The tadpoles of *R. catesbiana* spend two winters in the larval stage. The legs do not begin to show until the second summer, during July and August. The frogs continue to grow for several years and may increase in size until ten years old. Compare the general habits, environment and tadpoles of the species of frog which you study in the laboratory with R. catesbiana. The general activities of the frog in which the whole body is more or less involved may serve as representing the physiological outlook in the time of Haller.

References in Movement and the Nature of an Organism.
CRAMPTON: The Doctrine of Evolution, Chapter I.
JORDAN AND KELLOGG: Evolution and Animal Life, Chapter III.
RAND: The Problem of Organization, Science, 1912, xxxvi, 803, No. 937.
SCHAFER, E. A.: The Nature, Origin, and Maintenance of Life, Science, 1912, xxxvi, 289, No. 923.
SPENCER: Principles of Biology.
VERWORN: General Physiology.
References to Amphibia.
COPE: Batrachia of North America, 1889, Bull. U. S. Nat. Mus., No. 34.
DICKSON: The Nature Library, Frog.
ECKER: The Anatomy of the Frog.
GADOW: Amphibia and Reptilia.
HOLMES: The Biology of the Frog.
WRIGHT: Life Histories of the Anura of Ithaca, N. Y., Carnegie Pub., No. 197.

CHAPTER II.

ORGAN SYSTEMS—SCOPE OF BIOLOGY.

Digestive Canal.—The digestive organs of the frog consist of a hollow tube or canal and connected with it relatively solid glands. The digestive tube begins with the mouth and ends with the anal opening. The mouth is edged with lip-like folds of skin and many short conical teeth on the upper jaw. The opening itself is relatively large compared with the size of the whole animal, this enables it to eat large tadpoles and small frogs. The teeth are not used in tearing or grinding the food but rather assist in holding it, when once seized. The tongue is attached at the tip of the lower jaw and is thrown out by the action of muscles forcing lymph into the tongue. On the roof of the mouth are found the vomerine teeth and beside them the internal nares. Near the angle of each jaw is the Eustachian opening which passes into what corresponds to the middle ear. After the tympanic membrane is removed, the solid, single ear bone, the columella, is seen and the short passage into the mouth. The mouth cavity narrows in the posterior region but continues as a tube into a short distensible esophagus. Just in front of this opening is the glottis leading into the lungs. The inner surface of the esophagus is folded and these folds continue into the stomach. There is no sharp boundary between esophagus and stomach. The anterior end of the stomach is wider than the esophagus and known as the cardiac region, and from this region it tapers into the posterior or pyloric end where a slight constriction, the pyloric valve, separates it from the intestine. Each region of the digestive tube has a characteristic shape, this is particularly true of the stomach, and an expert could readily isolate the correct drawing of a frog's stomach from that of any other vertebrate such as fish, snake, or man. The position, however, which it occupies in the body, its terminology, its cardiac and pyloric regions and pyloric valve are the same as in all of the vertebrates. Passing from the spindle-shaped stomach, the intestine is small, coiled, and uniform in diameter until the large intestine is reached, where it becomes much larger. A special name, cloaca, sewer, is given to the posterior region of the intestine because of its relation to the urinogenital organs, which simply means that this region is used by both the digestive and urinogenital organs as a common passage to the exterior.

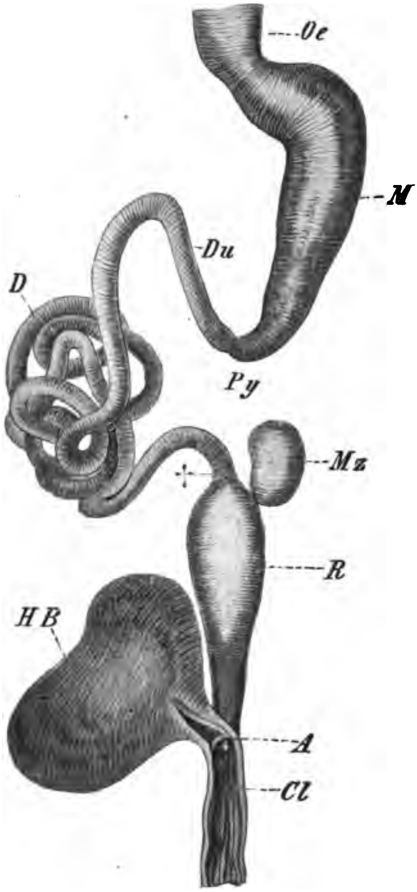


FIG. 9.—Intestinal tract of *Rana esculenta*. *A*, opening of the large intestine into the cloaca (*Cl*); *D*, small intestine; *Du*, duodenum; *HB*, urinary bladder; *Oe*, esophagus; *M*, stomach; *Mz*, spleen; *Py*, pyloric portion; *R*, large intestine. (After Wiedersheim.)

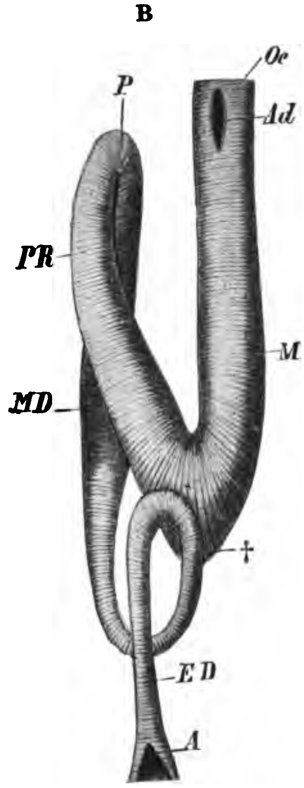


FIG. 10.—Intestinal tract of *Amia*. *A*, anus; *Ad*, approach to the pneumatic duct; *ED*, end gut; *M*, stomach; *MD*, midgut; *Oe*, esophagus; *P*, region of the pyloric valve; *PR*, pyloric part of the stomach bent at †. (After Balfour and Parker, from Wiedersheim.)

Digestive Glands.—There are probably no digestive glands in the mouth other than those that secrete the viscid fluid used on the tongue. The large liver, covering most of the digestive organs, and the small pancreas are true digestive glands that discharge their secretions through a single duct into the anterior end of the intestines. The liver which is red consists of three lobes, the small median lobe being covered by the heart. The whole liver is covered by a delicate membrane that holds it in place. A gall-bladder lies

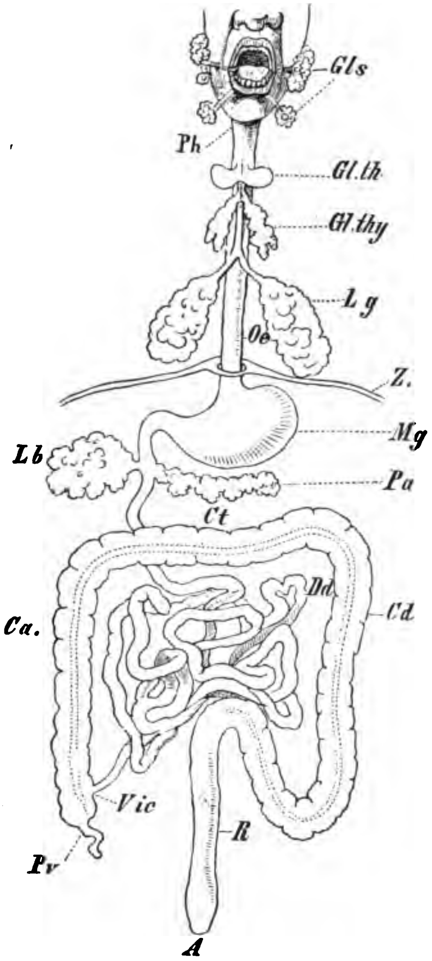


Fig. 11.—Diagram of the alimentary canal of man. *A*, anus; *Ca*, ascending colon; *Cd*, descending colon; *Ct*, transverse colon; *Dd*, small intestine; *Gls*, salivary glands; *Gl.th*, thyroid gland; *Gl.thy*, thymus gland; *Lb*, liver; *Lg*, lungs; *Mg*, stomach; *Oe*, esophagus; *Pa*, pancreas; *Ph*, pharynx; *Pv*, vermiform appendix; *R*, rectum; *Vic*, ileocolic valve; *Z*, diaphragm. (From Wiedersheim.)

between the right and left lobes (Fig. 12), and appears greenish when full of bile, the liver secretion. The gall-bladder is connected with the lobes of the liver by several minute ducts. These are the cystic ducts, some of which empty directly into the bile duct. The pinkish-white pancreas is located between the stomach and the first loop of the intestine. It is irregular in shape and through it the bile duct passes. Several pancreatic ducts discharge into the bile duct. Each gland as well as the intestine is held in place by a whitish, translucent membrane called the mesentery that is attached to the back. On the mesentery of the small intestine is the small ductless gland, the spleen.

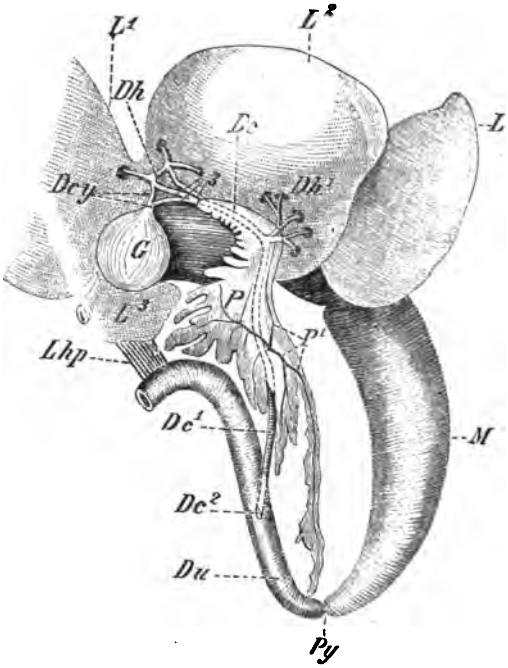


FIG. 12.—Pancreas and liver of *Rana esculenta*. *Dcy*, cystic ducts, which together with the hepatic ducts (*Dh*) form a network from which three collecting tubes arise, and these unite to form the common bile duct (*Dc*); the latter passes through the substance of the pancreas (*P*), receiving further hepatic ducts (*Dh*¹), and the pancreatic duct (*P*¹); at *Dc*¹ it becomes free from the pancreas, and passes back to open into the duodenum (*Du*) at *Dc*²; *G*, gall-bladder; *L*, *L*¹, *L*², the lobes of the liver turned forward; *Lhp*, duodenohepatic omentum; *M*, stomach; *Py*, pylorus. (After Wiedersheim.)

Respiratory Organs.—The skin and lungs are the important respiratory organs. The lungs are elongated, thin-walled sacs that are capable of great distention and their inner area is about equal to two-thirds of the total area of the skin. When the lungs are empty of air, they become inconspicuous, wrinkled masses. Experiments have shown that the frog can live when deprived of the use of either the skin or the lungs in carrying on the work of respiration. That this work of respiration can be carried on by two very different organs illustrates well how the frog introduces oxygen into the blood. The oxygen of the air may thus pass through the skin or lungs into the blood. This portion of the process is external respiration. The frog breathes by drawing the air into the mouth, which produces an oscillation of the throat; then the external nares are closed and the air in the mouth cavity is forced into the lungs. The movements of the throat do not correspond to the filling and emptying of the lungs. During hibernation in the mud the skin is the chief organ of respiration. During cold weather frogs can be kept alive for some days completely submerged in water. It should be clearly understood that the lungs, skin, and blood in taking oxygen from the air or water and in carrying it to all parts of the body, are acting in a mechanical-like fashion and are not carrying on true respiration, because respiration proper is one of the fundamental vital processes and can take place only in the living cells (see page 44).

Bohr: Ueber die Haut- und Lungenathmung der Frösche, Skandinav. Arch. f. Phys., 1899, Bd. x.

Klug: Ueber die Hautathmung des Frösches, Arch. Anat. u. Phys., Phys. Abth., 1884.

Krogh: On the Cutaneous and Pulmonary Respiration of the Frog, Skandinav. Arch. f. Phys., 1904, Bd. xv.

Urinogenital Organs.—It is customary to discuss these two sets of organs under one caption because of their intimate structural connections in the male. The small red kidneys are elongated, flat bodies (Figs. 13 and 14), similar in the male and female frog. A short ureter in the female carries the urine from the kidney to the cloaca. From the cloaca the urea passes by gravity into the ventral bi-lobed bladder.

On the median ventral surface of each kidney is the yellowish-white adrenal body. Each kidney is an organ that may be compared to a combined manufacturing and filtering plant. The removal of wastes from the blood is brought about in a twofold manner in the numerous microscopic tubules of which the kidney is composed. A single tubule consists of a filtering apparatus (the Malpighian body) and a glandular portion. In the Malpighian bodies wastes are strained out of the blood; while in the glandular portion of the tubules wastes are excreted.

The ovaries are usually very large, irregular organs surrounded by a thin membrane and attached to the back. There is no opening or duct leading from them. When the time arrives for the discharge of the eggs, they are set free in the body cavity through many openings in the wall of the ovary. The long coiled oviducts are separate from the ovaries and from each other, each has a wide opening just dorsal to the stomach into which (so far as we know) the eggs are forced by the general bodily movements. The posterior end of the oviduct is enlarged to act as a receptacle, uterus, for the eggs just prior to egg-laying; while most of the anterior portion is glandular, secreting the egg jelly (Fig. 14). The oviduct empties into the cloaca. In the male the parts are more closely united. The small spermary is supported by a mesentery that holds it near the anterior end of the kidney. Through this mesentery pass a number of minute tubes that carry the sperms into the kidney (Fig. 13). After the sperms reach the kidney they pass through and escape into the cloaca by using the regular duct of the kidney, the ureter. The ureter of the male becomes

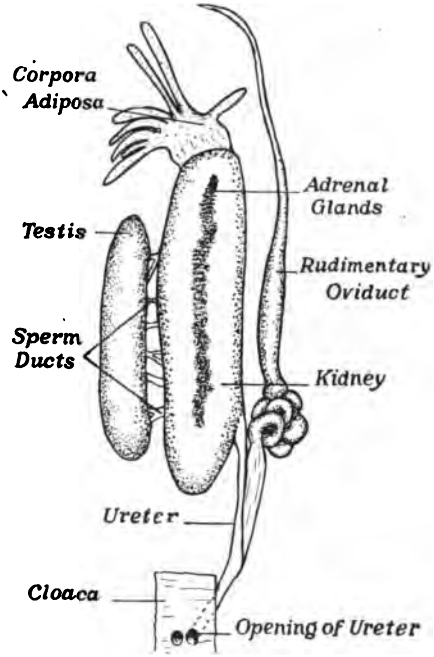


FIG. 13.—Male urinogenital organs of the toad.

enlarged near the posterior end for the reception of sperms. Because this duct carries both urine and sperms, it is called the urinogenital duct. Critical dissection usually reveals the presence of a small coiled structure just outside of the urinogenital duct which can be traced anterior to each kidney where it becomes minute (Fig. 13). This is a rudimentary structure, *i. e.*, one that was of use to some ancestor of the frogs but not now used. If the large oviducts of the female frog were greatly reduced in size, they would look just like these structures in the male frog which are designated rudimentary oviducts. There are many cases on record in the frog of finding small ovaries variously associated with the spermaries. The rudimentary oviducts and the occasional presence of partly developed ovaries suggest that

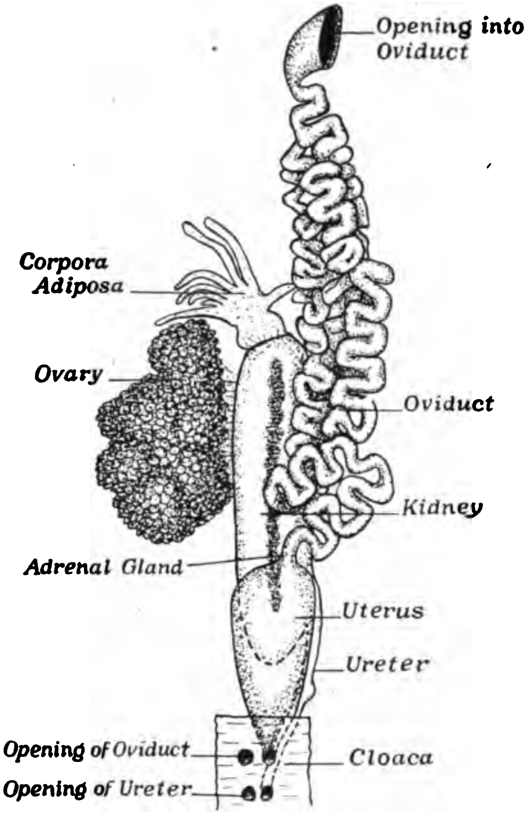


FIG. 14.—Female urinogenital organs of toad.

the ancestors of the frogs were hermaphroditic, *i. e.*, possessed both spermaries and ovaries. Attached to the anterior end of each kidney are the corpora adiposa (Figs. 13 and 14), which do not decrease in size until the period when the frog begins to grow eggs or sperms.

Cœlom.—All of these organs are located in a large cavity which is termed the cœlom. It is on the ventral side of the body and is a common cavity in all vertebrates.

Organ Systems.—In any description of a set of organs to which a single name can be given certain intimate relations are implied. While there are many different parts which may have widely different shapes, they all work in harmony to produce some single purpose, as the digestive organs in digesting food, etc. Here each organ does a given part of the whole work. The work is thus done better than if there were no such division into organs. This using of many organs in carrying out a single general work of an organism is characteristic of all complex plants and animals, and results in a system of organs. Each system of organs assumes a given work for the benefit of the organism, so that it is often described under the heading of physiological division of labor. This same principle describes accurately the difference between a complex civilization where most people are experts, that is, each does some one thing well, from that of barbarians where each does many things and these but indifferently. In the former case each is dependent upon many others for existence; while in the latter a single family often sustains existence and provides for all of its own wants. The frog would soon die if any of the organs were permanently removed from any of its organ systems. It would be likewise difficult for us to exist if those who supplied us with certain articles ceased to exist. This analysis of the body of the frog into definite organs marks the method of study made famous by Cuvier who gave to the morphological study of organs such an importance that it may well stand for the second stage in the development of biology.

Scope of Biology.—Biology aims to ask four general questions about an organism: (1) What is it? (2) What does it do? (3) How does it arise? (4) How did it come to have its present form and relations? Each of these questions leads into rather well-defined lines of study. The discussion thus far has centered mainly around the first question. This study of the shape, structure and relation of parts is known by the technical term *morphology;* while the answer to the second question seeks to state the relation of these parts to the vital processes and is called likewise by a special term *physiology*. A suitable answer to the third question involves the study of how each single organism comes into existence and grows into a mature organism, and this branch of biology is called *embryology*. The fourth question is more general and comprehensive, for it includes the history of the frog family, and must needs consider the record left in the rocks as well as all of historic time and the relation of its environment as an influence on the development of the frog family. This phase of biology is called *evolution*. Every organism may be studied from these four points of view, but these are very general terms and the science of biology has made marvelous progress, so that each of these great subdivisions is again divided into special departments of biological learning, a mere statement of which will suffice.

- Biology
  1. Morphology
     - Anthropology
     - Anatomy
     - Histology
     - Taxonomy
  2. Physiology
     - Physiology, general and human
     - Psychology
     - Sociology
  3. Embryology
  4. Evolution
     - Heredity
     - Variation
     - Distribution
     - Racial history

Applied to medicine, forestry, agriculture, domestic science, physical education.

CHAPTER III.

PHYSIOLOGY OF DIGESTION IN THE FROG.

Need of Food.—While the frog cannot tell us in words that he requires food, yet we are as certain that he does as if he could say, "I am hungry." In fact that is just what his actions mean when we make him jump along the bank after a baited hook. Because the frog is an animal and because man is an animal in just the same sense, we are justified in using many facts that we know about man in our attempt to explain the work of the various organs of the frog. In this sense the chapter heading might read the "physiology of digestion of animals."

The need for food is fundamental with all living things because they all use energy in living, and energy is something that is not created but exists all of the time in one form or another. The frog as a typical animal shows the relation of this energy as it exists in the form of food. The frog expends energy in three conspicuous ways: (1) In every movement of the body there is an expenditure of energy in the contraction of the muscles. The frog can be made to jump continuously for a time but soon the jump grows short and it needs a stronger stimulus to cause it, after a little longer time the frog refuses to jump, the muscles are, so far as general observation goes, just the same as when the first jump was made but after this severe muscular exertion there is a condition of exhaustion until the muscles can be supplied with more food. It is well known that the simple elements which unite to make proteins or carbohydrates do not act as a food when fed to the frog, but that they must be combined into one of the three classes of foods. This can only mean that some definite agency has been at work to combine the many chemical elements found in the foods. In this respect the frog is like all other animals in requiring that its food be ready-made, as it has no power to manufacture food out of the raw chemical elements. (2) The need for energy arises because of the periodic production of a large number of eggs by the female and many sperms by the male. Both eggs and sperms are living and as such have been grown. The production of the living germinal substance, especially the egg, utilizes a large amount of energy that is indirectly supplied by the food eaten. (3) The body of the frog, while in a large measure subject to the surrounding temperature, does utilize energy to some extent in the production of heat. This keeping the body warm is a more conspicuous expenditure of energy in birds and mammals where a constant bodily temperature is maintained.

Unless the frog can meet these three needs of the body it soon dies; that these three needs are supplied, there is abundant evidence. The laboratory study showed that foods are commonly divided into proteins, carbohydrates, and fats, to these three must be added water and certain salts which are either taken separately or as a part of the foods.

Proteins.—One of the chief constituents of living cells is protein. This is a complex substance always containing carbon, hydrogen, nitrogen, oxygen; while sulphur, phosphorus, iron, copper, iodine, manganese and zinc are of frequent occurrence in the protein molecule. These several chemical elements exist in about the following percentages:[1] Carbon, 40 to 55 per cent.; hydrogen, 6 to 7.3 per cent.; oxygen, 19 to 24 per cent.; nitrogen, 15 to 19 per cent.

The frog secures his proteins from the flesh that he eats, as all lean meat belongs to this class of foods. As the frog is not very particular in the selection of his food, he may get some plant proteins. Recently the biological chemists agreed upon the following classification for plant and animal proteins: Simple proteins, conjugate proteins, and derived proteins.

The simple proteins are such substances as albumen in egg and some vegetables, or the globulins, fibrinogen or plant vitellin. The simplest proteins are the protamines found in fish sperms. The conjugate proteins have the protein molecule united with some molecule or molecules other than a salt. The conjugate proteins include the nucleoproteins in which nucleic acid is united with the protein, glycoproteins which contain a carbohydrate, phosphoproteins, hemoglobins where hematin is the combining form, and lecithoproteins. This group of the proteins is subdivided into many distinct substances, the discussion of which belongs to organic chemistry.

The third class of proteins is the derived proteins which should not be confused with the natural proteins existing as simple and conjugate proteins. These are all derived through digestion. As the protein molecule is thus transformed, and becomes soluble, certain stages are recognized, and each of these gives definite chemical reactions that enable the expert to recognize six classes.

---

[1] For the significance of these percentages consult Chapter I, Chittenden, Nutrition of Man.

Proteins are so complex chemically that their formula is not accurately known, one writer in order to show the complexity of egg albumen, has proposed the following empirical formula: $C_{204}H_{322}N_{52}O_{66}S_2$.

Proteins are non-diffusible, are coagulated by heat and are usually called nitrogenous foods. Explaining their use to the frog in terms of what is known about higher animals, it can be said that proteins perform the definite work of renewing the worn-out and exhausted parts of the organs. In fact no other kind of food can do just this work nor does any other class of food stand in such close relation to the vital processes of the frog. Oxygen, nitrogen, and all of the other elements exist in the air but they cannot be used in the repair of the organs because they are not combined into protein molecules.

Carbohydrates.—The word carbohydrate refers to a group of bodies made in the cells of plants. Carbohydrates contain carbon, hydrogen and oxygen; with the hydrogen and oxygen combined in the same proportions as water, H_2O, this is shown in the starch molecule, $C_6H_{10}O_5$, where one may expect to find about 44.4 per cent. of carbon, 6.2 per cent. of hydrogen, and 49.4 per cent. of oxygen. The carbohydrates are classified as: Monosaccharids, which contain the most important simple sugars such as dextrose ($C_6H_{12}O_6$); disaccharids, such as maltose from cane-sugar and lactose from milk-sugar ($C_{12}H_{22}O_{11}$); and polysaccharids of which starch, dextrin, and cellulose are best known $(C_6H_{10}O_5)_n$.

Fats.—Fats are formed of the same elements as carbohydrates but there is less oxygen in the fat molecule. Because of the absence of nitrogen these last two classes of foods are called non-nitrogenous foods. Fats contain about the following proportions: Carbon, 76.5 per cent.; hydrogen, 11.9 per cent.; oxygen, 11.5 per cent.

Fats are widely distributed in organic nature. They are stored in the seeds, roots or fruit of plants and all animal tissues contain a varying amount, being especially abundant in bone, marrow, and adipose tissue.

Some of the common animal fats are stearin in beef suet and butyrin in butter. Most fat is a mixture of several individual fats. "Thus the ordinary mutton fat contains more tri-stearin and less tri-olein than pork fat." Human fat contains from 67 per cent. to 85 per cent. of tri-olein.

The non-nitrogenous foods are easily diffusible and serve as the natural fuel foodstuffs of the body. They cannot serve for renewing the exhausted parts of an organism. The frog does not secure a large amount of carbohydrate except as vegetable matter is eaten, but it does get plenty of fat associated with the lean meat of insects, tadpoles, frogs, etc.

Digestion.—It is easily recognized that the food of the frog after it has been eaten is not within his body proper but simply in the hollow digestive tube. It is entirely possible for food to pass through the frog and not yield any energy simply because it has not entered into the body of the frog. Most of the foods have to undergo important changes before they pass through the walls of the digestive tube. These changes are induced by what are called digestive secretions. A secretion is defined in biology as follows: *Any substance which is the product of living cells and serves some useful purpose in the economy of organisms may be called a secretion.* In this sense every secretion has been a part of the living substance of some part of an organism and is usually produced in what are known as glands, such as the liver or pancreas, in other instances the gland is a small part of the inner wall of the stomach. The ovaries and spermaries are both glands, although their secretion takes the form of cells, ova and sperms, instead of a fluid. The digestive secretions are known as enzymes, a term coined by Kuhne, in 1878, because of the nature of the changes that they are capable of producing in the food. In chemical terms we describe *an enzyme*[1] *as a catalytic agent formed in the living organisms.* Such bodies initiate and accelerate chemical changes in another body without undergoing any change themselves. Fischer speaks of the specific action of enzymes, that is, the capacity of digestive enzymes to attack one substance and not another which may even be closely related. Halliburton illustrates the work of an enzyme by saying: "We may roughly compare enzyme to an ill-disposed person who comes into a roomful of good-natured people and who succeeds in setting them all by the ears. He has produced a change in them without undergoing any change himself by his mere presence. He is, moreover, able to repeat the process over and over again in fresh roomfuls *ad infinitum.*"

The stomach of the frog contains many glands that produce gastric juice which consists of a small amount of hydrochloric acid and the enzyme, pepsin (Fig. 15). Pepsin acts on the proteins only and transforms them into a substance that will pass through the walls of the digestive tube. It is difficult to understand how this change is brought about and especially the extent of the changes which take place in the protein molecule up to the time that it takes the form of an amino-acid, for the pepsin is the same as when it was set free from the glands and poured into the stomach, but the molecule of protein has undergone a great change, the details of which are too technical for this work. The action of an enzyme on a food is known as fermentation, and since pepsin acts just as readily in a test-tube as in the stomach, *i. e.*, apart from the living gland that produced it, it is called an unorganized or non-living ferment. All of the digestive ferments are unorganized.

---

[1] What are enzymes? Horowitz, The Scientific Monthly, March, 1918.

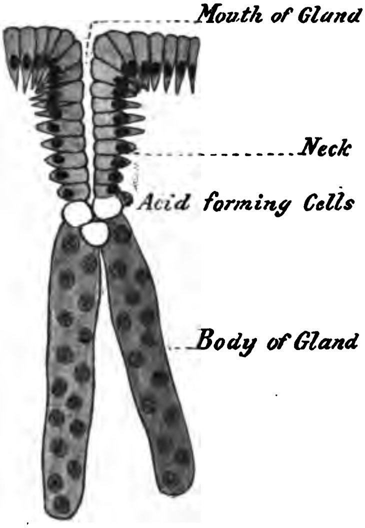


FIG. 15.—Gastric gland of frog.

When the gastric enzyme has done its work the residue of undigested proteins, the fats and the carbohydrates pass into the intestine to come in contact with the alkaline secretions of the pancreas and liver where the process of digestion is completed. The pancreas of the frog has the faculty of secreting three distinct enzymes, each specific in its action. These are trypsin, which converts proteins into amino-acids, amylopsin, which changes starches into sugars, and steapsin, which causes a splitting of fats into fatty acids. The bile assists in emulsifying the fats, *i. e.*, the fat becomes transformed into minute globules, which gives a milky appearance to the liquid. The several digestive enzymes act as accelerating agents merely, for all of these changes would eventually take place if given sufficient time. The speed with which these changes take place is much greater under the influence of the living cells than when they occur in a test-tube for example. Mathews says: "Living matter is hence peculiar in the speed with which these hydrolytic, oxidative, reduction or condensation reactions occur in it; and it owes this property to various substances, catalytic agents, or enzymes, found in it everywhere." (*Physiol. Chem.*, p 10.)

The digested food is absorbed through the walls of the digestive tube (Fig. 16) and passes into the blood where its course will be followed in the next chapter. The use of the word absorb does not convey an accurate idea of just what is meant by the process. In this passing of food through an animal membrane, the lining epithelium of the digestive walls, there is the physical process of osmosis to which must be added probably some action on the part of the living protoplasm of these cells. Just what this action is cannot be fully stated.

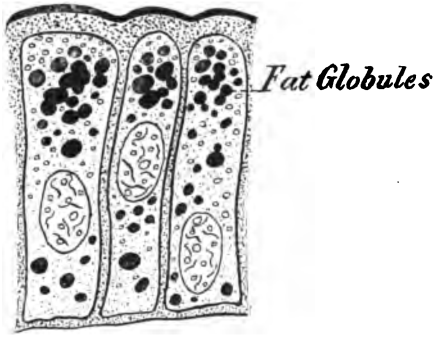


FIG. 16.—Epithelium of frog, showing fat globules passing through the living epithelial cells of the intestine. (After Krehl.)

The fate of the digestive secretions illustrates one of the strange wastes of Nature. After the several foods have been rendered soluble and diffusible, in other words, digested, we are led to believe that there is just as much of the several enzymes as when the digestive process began. The body of the frog absorbs but a small portion of them, and the remainder pass from the body with the indigestible parts of the food. If Nature provided some way of collecting and using again these secretions, there would be a large economy in the life of every animal. The need for food and the principles of digestion are common to all forms of life.

CHAPTER IV.

CIRCULATION—METABOLISM.

Heart.—The blood of the frog follows well-defined routes as it travels to all parts of the body, and in this particular the frog belongs to the higher rather than to the lower class of animals. These routes of travel for the blood are the arteries, which carry it from the heart, and the veins, which return it to the heart. The heart is a most interesting organ because of its origin and work. Could you observe the heart as it first begins to beat and force blood along in the embryonic bloodvessels, you would not recognize in it the adult, conical, compact heart but rather an elongated branched structure which passes through a series of complicated changes before the adult structure is reached. This wonderful propelling organ for the blood is a gradual growth, and it took Nature a long time to evolve it.

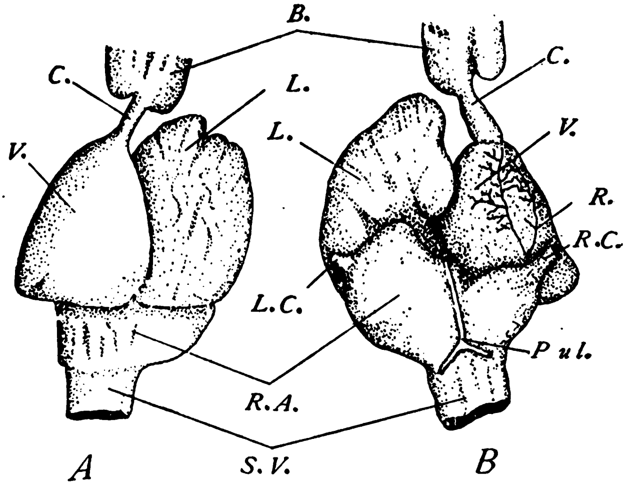


FIG. 17.—The heart of *Cryptobranchus*. *A*, ventral; *B*, dorsal aspect. *B.*, bulbus arteriosus; *C.*, conus arteriosus; *L.*, left auricle; *L.C.*, left anterior vena cava; *Pul.*, pulmonary; *R.*, coronary vessels; *R.C.*, right anterior vena cava; *S.V.*, sinus venosus; *V.*, ventricle. (Reese.)

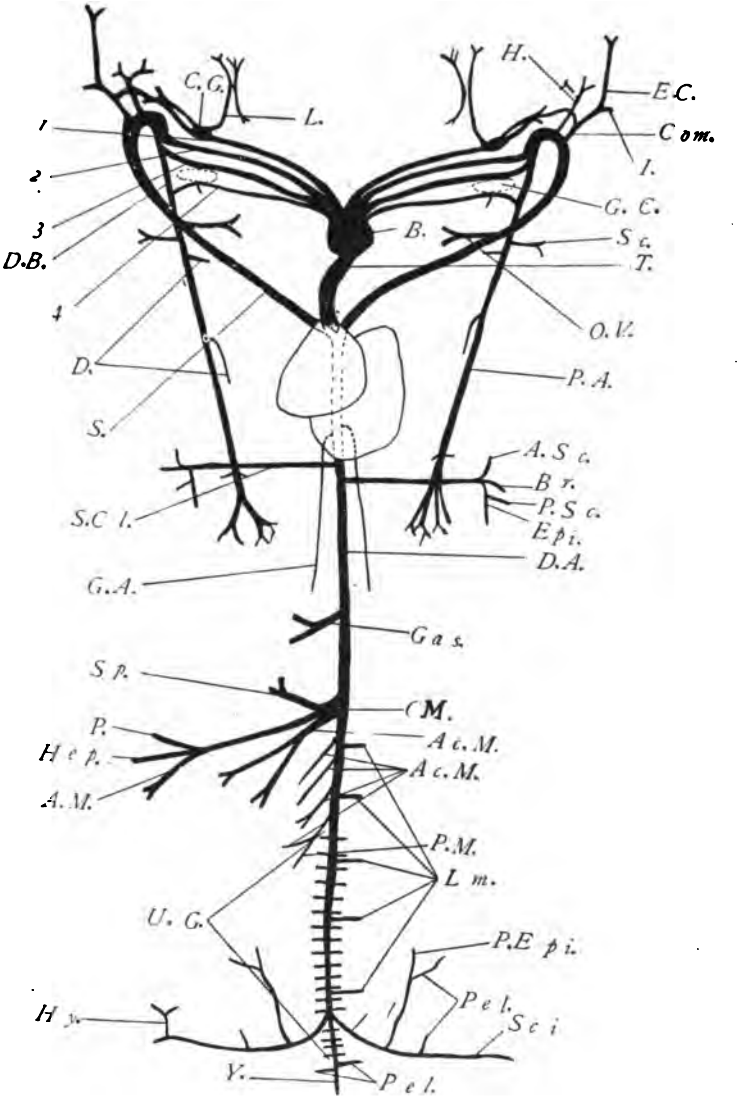


FIG. 18.—The arterial system of *Cryptobranchus*, ventral aspect. *A.M.*, anterior mesenteric; *Ac.M.*, accessory mesenteric; *A.Sc.*, anterior scapular; *B.*, bulbus arteriosus; *Br.*, brachial; *C.G.*, carotid gland; *C.M.*, celiacomesenteric; *Com.*, ramus communicans; *D.*, to dorsal region near lungs; *D.A.*, dorsal aorta; *D.B.*, ductus Botalli; *E.C.*, external carotid; *Epi.*, epigastric; *G.A.*, anterior·genitals; *Gas.*, gastric; *G.C.*, gill cleft; *H.*, hyoid; *Hep.*, hepatic; *Hy.*, hypogastric; *I.*, internal carotid; *L.*, lingual; *Lm.*, lumbar; *O.V.*, occipitovertebral; *P.*, pancreatic; *P.A.*, pulmonary; *Pel.*, pelvic; *P.Epi.*, posterior epigastric; *P.M.*, posterior mesenteric; *P.Sc.*, posterior scapular; *Sc.*, scapular; *Sci.*, sciatic; *S.Cl.*, subclavian; *Sp.*, splenic; *T.*, conus arteriosus; *U.G.*, urogenitals; *Y.*, caudal; *1, 2, 3, 4,* first to fourth branchial arches. (Reese.)

The work of the heart is to force the blood continually through the bloodvessels. It contracts slowly as compared with the human heart, but evenly and uniformly during the active season; while during hibernation the beats are feeble and slow. The fact that a structure exists which works regularly day and night, week after week, year after year, and only rests seconds or fractions of a second at a time is a constant source of wonder.

The frog's heart is situated just anterior and ventral to the liver. It is surrounded by a thin membrane, the pericardium. The heart is made up of three parts: (1) The conical ventricle, with the point directed posteriorly; (2) the two auricles, right and left, which are in front of the ventricle. A thin membrane divides the two auricles into separate chambers. The right auricle receives venous blood from the body, and the left auricle, oxygenated blood from the lungs. Both auricles empty their blood into the single ventricle, which in turn contracts and fills the arteries. As the blood leaves the ventricles it enters the large bulbus arteriosus which forms two branches that give rise to the aortic arches (Fig. 18). The details of the heart, arteries, and veins should be worked out in the laboratory and compared with Figs. 17, 18 and 20.

Blood.—The blood of the frog consists of corpuscles and plasma. There are three kinds of corpuscles: (1) The red, which are oval in outline and contain hemoglobin. The work of the hemoglobin is to carry the oxygen from the organs of respiration to all parts of the body. (2) The white corpuscles, smaller than the red and irregular in shape. They are factors in the clotting of blood (Fig. 19), the destruction of foreign bodies such as disease germs, and the removal of degenerating parts. The white blood cells, or phagocytes, change their form much as an ameba does, and consequently have the power of independent locomotion, so that they pass through the thin walls of the capillaries and out into the spaces between cells and are found in all parts of the frog. As they thus migrate around in the body minute foreign particles, such as bacteria, are met with and eaten (phagocytosis). Their method of eating will be better understood after the study of the protozoa, where a similar method of eating is the usual process. These white cells also help to remove broken bits of tissue, as in the removal of the degenerating tail. (3) The spindle-shaped corpuscles are colorless except during the spring when they acquire hemoglobin and are transformed into red blood corpuscles. They are smaller than the true red corpuscles and may change their shape somewhat. Besides forming new red cells, they assist in the clotting of the blood. The blood corpuscles wear out like the other parts of the body and have to be renewed. The marrow of the bones is one of the most important sources for the origin of new blood corpuscles. The plasma of the blood is straw-colored or else colorless in appearance. It contains the various transformed foods, water and salts, as well as the waste products of the body; hence its chemical composition varies from day to day and from season to season, being influenced largely by the animal's amount of activity and its food supply.

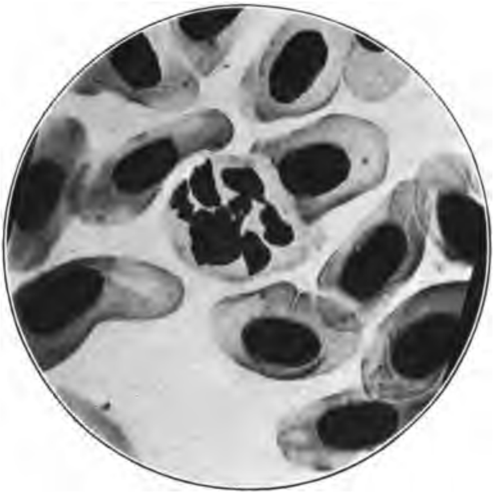


Fig. 19.—Photomicrograph of blood of necturus. Compare the oval nuclei in the red corpuscles with the polymorphic nucleus of the white corpuscle in center of figure.

The lymphatic system does not occupy definite lymph vessels but consists of several large, irregular-shaped lymph spaces. Some of these can be easily dissected and their boundaries determined as the skin is removed. These subcutaneous spaces are separated by thin septa of connective tissue. The colorless lymph flows into the blood through the four lymph hearts. A pair dorsal to the anal opening can easily be seen beating in the living or recently killed frog.

Respiration.—The carrying of food to all parts of the body is but one work which the blood does. A second is its relation to respiration; the presence of hemoglobin in the red blood corpuscles is for the sole purpose of uniting chemically with the oxygen as the blood flows through the lungs or close to the skin. The oxygen becomes loosely combined with the hemoglobin with which it remains until a place in the body is reached where there is a scarcity of oxygen, then the oxygen is released from the hemoglobin to pass through the walls

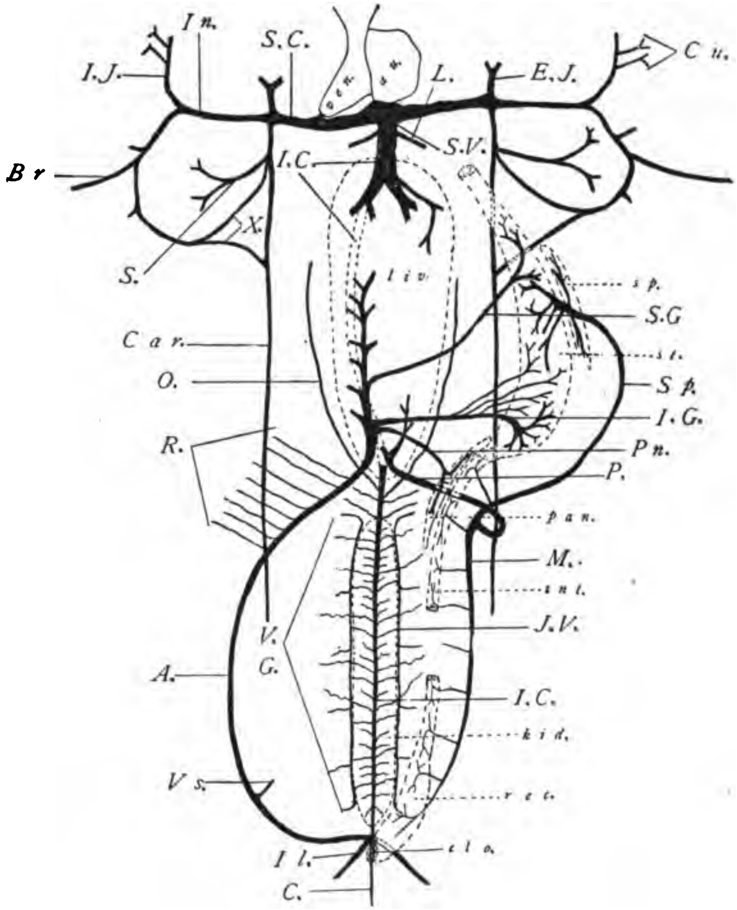


FIG. 20.—The venous system of *Cryptobranchus*, ventral aspect. *A.*, abdominal; *Br.*, brachial; *C.*, caudal; *Car.*, posterior cardinal; *Cu.*, cutaneous; *E.J.*, external jugular; *G.*, genital; *I.C.*, inferior cava; *I.G.*, inferior gastric; *I.J.*, internal jugular; *Il.*, iliac; *In.*, innominate; *J.V.*, vein of Jacobson; *L.*, pulmonary; *M.*, mesenteric; *O.*, oviduct; *P.*, portal; *Pn.*, pancreatic; *R.*, parietals; *S.C.*, superior vena cava; *S.*, from shoulder; *Sp.*, splenic; *S.V.*, sinus venosus; *V.*, vertebral; *Vs.*, from urinary bladder; *X.*, plexus. (Reese.)

of the capillaries to take part in the vital activities of that region. When the oxygen first unites with the hemoglobin it gives it a bright red color which darkens as the oxygen participates in the vital processes. Coincident with this taking of oxygen to all parts of the body is the carrying away by the plasma and hemoglobin of a waste substance known as carbon dioxide. The carbon dioxide is carried to the lungs or skin where it leaves the body of the frog, passing into the air. The frog then is continually taking oxygen from the air and giving off a waste substance, carbon dioxide, to the air. If certain other agencies were not at work, we could easily believe that after a time the oxygen content of the air would become so much reduced that breathing for all animals would become difficult or impossible. In applying the term waste to carbon dioxide a definite meaning is given in biology. *Waste substances are such as have once been a part of the living body and are produced as a result of some expenditure by the living organism. In this sense waste and excretion have the same meaning.*

The frog, like all living things (except certain bacteria), uses this oxygen in a definite manner which is characterized as one of the fundamental vital processes. Lavoisier, in 1792, pointed out that the use of oxygen in respiration was a chemical process. That heat was produced by living things and ceased with their death was known from the earliest times. But not until the discovery of oxygen in 1771 was it possible to understand how this heat was formed in living things. This suggestion of Lavoisier is really the beginning of the modern physiological study of biology, because his suggestion showed that chemical elements and compounds behave in a definite manner in living things, thus furnishing a scientific starting-point for such explanations. The value of this scientific point of view in this connection is well illustrated by the following: Oxygen in the atmosphere exists as O_2 molecular oxygen, and as O_3 ozone. When these two chemical bodies are brought in contact with the living protoplasm in respiration more heat comes from O_3 than O_2. There is thirty-two thousand times as much free energy in a given amount of ozone as in the same amount of oxygen, so that the living cells are actually supplied with more energy from ozone than from oxygen.

In any discussion of respiration it must be remembered that respiration is a vital process that takes place within the living protoplasm and as the oxygen reacts on carbon, energy in the form of heat is supplied. This is known as oxidation.

Metabolism.—The nature of the several excretions and the character of the food in the blood tell much concerning the vital processes. More can be learned in an advanced course in physiology, but even there a great deal is not understood. There seems to be a number of constructive or up-building agencies, in the form of internal enzymes, which serve to make the combinations of the nitrogenous and non-nitrogenous molecules more like those that exist in living substance, but there is still a wide difference between the two, and science has not yet discovered just how the food becomes living. How long the transformed food remains a part of the living substance is a matter of conjecture. The changes which initiate the breaking down of the living substance and the formation of waste products are also unknown; yet the two processes are taking place all the time in the body of the frog, the one in the nature of construction or up-building, the other destruction or tearing down. To cover these two widely different processes in the body the general term of metabolism is used. "*Metabolism designates that complex of chemical changes in living organisms which constitute their life, the changes by which their food is assimilated and becomes a part of them, the changes which it undergoes while it shares their life, and finally those by which it is returned to the condition of inanimate matter.* Gathered together under this one phrase are some of the most intricate and inaccessible of natural phenomena." (Chittenden.) The single word metabolism is used to indicate one of the distinguishing characters of all organisms. In using the term in this way it is understood to include the changes indicated in the definition; and while these are many and divergent, yet they are a part of one vital process. Thus used metabolism serves to mark off sharply the activities of living substance from all forms of activity in non-living matter and is a distinguishing feature of living matter only.

Hibernation and starvation are two closely allied phenomena. In both instances the organism sustains itself by utilizing energy stored within the body. Until the discovery of internal enzymes, little was known concerning the physiology of these conditions. It has been known for some time that the muscles of the frog become lighter during hibernation but what the agent was that enabled the frog to withdraw energy from muscles was not understood. The writer has experimented with some fish and has been able to keep one without food for twenty months. The result was that the muscles became very much reduced and the fish was hardly able to move. A similar condition exists in human beings in the case of a fever or tuberculosis. The body becomes very much lighter and emaciated. What has become of all of the energy stored in the muscles in all of these illustrations and how has it been utilized?

The most widely accepted theory at present is that the internal enzymes may reverse their action when there is a demand for food-energy and attack the muscles. This is known as the reversibility of

FIG. 21.—Johannes Müller, 1801–1858. The most famous physiologist of his time. He introduced the comparative study of physiology and gave especial attention to the physiology of organs. His work marks an epoch in the development of the science of biology. (From Locy's Biology and Its Makers.)

internal enzymes. In these cases of hibernation, starvation and emaciation from sickness, it is probable that the internal enzymes are the agents that release the food energy that exists as muscle which thus freed is carried by the blood to such parts of the body as demand food to keep the organism living. A chemical examination of the blood of a starved fish and one recently caught revealed the fact that there was about the same amount of food products in each.

Metabolic Water.—That water is necessary to life has been known for a long time. During development it is the most abundant constituent, ranging from about 40 per cent. to nearly 100 per cent. This demand for water enters into the very life of the cells and is satisfied from imbibed water and from metabolic changes in the food. The imbibed water serves to dissolve nutrients, to act as a medium for their distribution, to remove injurious waste products and to influence temperature to some extent by the amount of evaporation.[1]

The metabolic water is chiefly derived from the oxidation of nutrients. The carbohydrates, fats and proteins all contain hydrogen and their complete oxidation as they are built up into living protoplasm or take part in the several vital processes produce a certain amount of water. "Thus 100 parts of cellulose or starch $(C_6H_{10}H_5)_n$, containing 6.17 per cent. of hydrogen, give 55.5 parts of water. Most fats yield more than their weight of water, while proteins when completely oxidized give from 60 to 65 per cent. of water. (Babcock.) The several nutrients are oxidized in the cell protoplasm. Here the formation of water in the protoplasm gradually and continuously renders the nutrient solution within of less density than that without. Such a difference in concentration insures a constant movement by osmosis toward the points where foods are needed.

The rate of oxidation is greater in animal cells than in plants, consequently there is a greater amount of waste in animals. This is especially the case with soluble products arising from protein metabolism. These are excreted through the kidneys in the urine in the form of urea in fishes, amphibia and mammals; while in birds, reptiles and insects most of the nitrogen waste is in the form of uric acid or its ammonia salt. These are practically insoluble in the body, so that the need for water in such animals is much less because the uric acid is not as poisonous nor its accumulation as dangerous.

---

[1] Babcock, S.: Metabolic Water: Its Production and Role in Vital Phenomena.

In all animals the protoplasmic need for water is largely supplied by the metabolic water, and during hibernation the metabolic water is sufficient for all the vital needs. In such cases it is derived from the food energy stored in muscles and fat. In a similar way insects that live upon air-dried food and desert animals are able to supply their bodies with the requisite amount of water.

In this chapter it has been shown how certain organs work and the importance of this work to the organism as a whole. This is the period of Müller in the growth of biology.

CHAPTER V.

TISSUES AND CELLS OF THE FROG.

Histology.—Anatomy or gross morphology enables one to learn much about the shapes and relations of most of the organs of the frog but it tells very little about the parts of the organs themselves. In the analysis of the minute structure of an organ the method is essentially the same as in the study of anatomy except that one must employ some magnifying instrument to enlarge the minute parts in the organ. The compound microscope is used for this purpose. The preparation of an organ for this minute analysis illustrates how biology utilizes the science of chemistry, for without the chemical information now available the details of an organ as well as many other important biological facts would be unknown. The general term histology is used for both the preparation of an organ and its subsequent analysis by the aid of the microscope. In the preparation of the organ for histological study several distinct chemical processes are employed, usually in the following order: (1) Killing and fixing all of the parts of the organ in as normal a relation and shape as possible. (2) Hardening the many parts so that they will retain their characteristic outline, etc. (3) The staining of all the parts so as to differentiate them as a result of their different reactions to stain. It requires much skill to be able to secure the best possible results in the use of the many stains now employed. (4) The parts of the organ must be cut into thin, nearly transparent sections if the microscope is to be employed in studying them. Each of these several processes requires much detailed technical work, each step of which must be accurately done or the result is a failure. The science of histology is very technical, although fundamental to the study of embryology, pathology, and bacteriology. The present chapter aims to serve as an introduction to the histological analysis of an organ.

Histology of Intestine or Stomach.—When the microscopic slide of the stomach or intestine was studied, it was an easy task to recognize three general layers. Each layer was characterized by having many very small structures known as cells. These cells in the inner layer were elongated and arranged in rows. In a similar manner the shape and arrangement of the cells in the other layers were made out (Fig. 22). These different layers are known as tissues and from a morphological standpoint a tissue is defined as a group of similar cells, similar in shape and arrangement; but this is only part of the definition, for these similar cells must do a similar work for the organ. A tissue is therefore usually defined as a *group of similar cells having a similar function.* The definition should always be recognized as having these two aspects. All the organs of the frog are made up of several tissues, and what is true of the frog is true of all complex animals, so that an organ is defined as a group of tissues united in order to do a given work for the organism. Bichat advanced our knowledge of living things by his famous studies upon the composition and work of tissues.

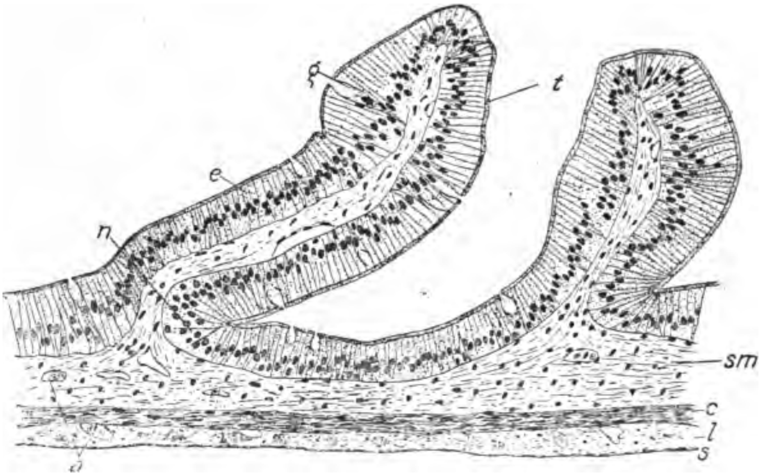


FIG. 22.—Transverse section through the intestinal wall of *Cryptobranchus* to show the details of two longitudinal folds. *a*, bloodvessels; *c*, circular muscle layer; *e*, columnar epithelium forming the layer; *g*, goblet cells; *l*, longitudinal muscle layer; *n*, group of young cells; *s*, serosa; *sm*, submucosa; *t*, top-plate or striated border. (Reese.)

Tissues.—In all of the higher organisms the body consists of a number of distinct tissues which have been arranged into four classes based on their function and intimate structure. These are (1) epithelial; (2) connective or supporting; (3) muscular; (4) nervous.

1. *Epithelial Tissues.*—The epithelial tissues are the oldest and the first to appear in the embryonic development. They have undergone but little modification in order to perform their several functions. These tissues are found in the skin of the frog, lining the mouth and entire digestive canal, lining the lungs, and ducts of the

entire excretory and reproductive systems. They also constitute the glandular cells in the liver, pancreas. kidneys, ovaries and testes of the frog. Their most important work is to form a protective covering to surfaces, both exterior and interior, to avoid drying, to act as a buffer against mechanical injury, and to prevent infection by disease germs. Their very position makes them the most important structures in secretion and excretion in glands (Figs. 24 to 26), and in receiving stimuli from the external world. Epithelial tissue is subdivided into (*a*) flattened or squamous (Fig. 23); (*b*) columnar (Fig. 25); (*c*) ciliated (Fig. 24). Epithelial tissue has a small amount of intercellular substance. The glands in the frog consist of two general classes defined as unicellular and multicellular. In the unicellular gland a single epithelial cell takes on the function of producing a secretion (Figs. 24 and 25). Multicellular glands involve a number of epithelial cells that may undergo considerable change in shape. The two main kinds of multicellular glands are the tubular and acinous (Fig. 26).

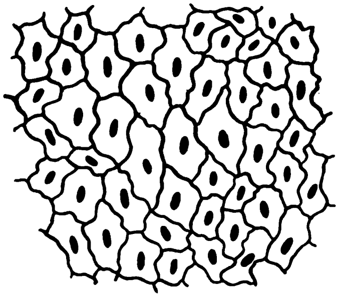


FIG. 23.—Squamous epithelium from the mesentery of the frog.

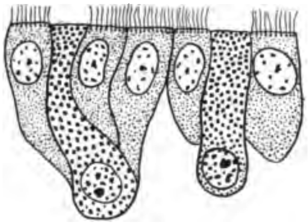


FIG. 24.—Ciliated epithelial cells from the roof of the mouth of the frog. Note the two unicellular gland cells packed with coarse granules.

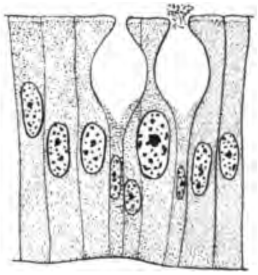


FIG. 25.—Columnar cells from the lining epithelium of the small intestine of the frog. Two unicellular gland cells are also shown.

2. *Connective Tissues.*—Connective tissues embrace a large number of tissues whose main function is to bind the parts of the organism together. They are found in the deep parts of the body, and gain their importance chiefly through the intercellular substances. One of their primary functions is to fill the spaces between organs. The

four following kinds of connective tissue are recognized: (*a*) fibrous; (*b*) adipose; (*c*) cartilage (Fig. 27); (*d*) bone (Fig. 28). By some the blood is regarded as a modified form of connective tissue, the plasma being regarded as the intercellular substance and the corpuscles, the living part of the tissue; while others regard the blood as simply a nutritive fluid of which there are two kinds: (*a*) the blood proper and (*b*) the lymph.

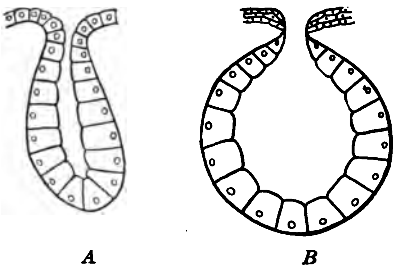


FIG. 26.—*A*, tubular gland from tongue of frog; *B*, acinous gland from skin of frog.

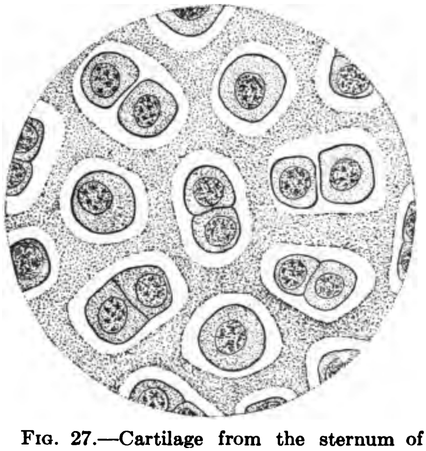


FIG. 27.—Cartilage from the sternum of the frog. Notice the large amount of intercellular substance shown by "stippling" which is one of the important points to notice.

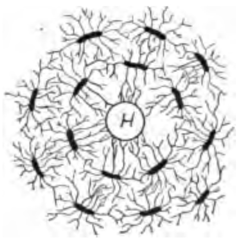


FIG. 28.—Diagram of finer structure of bone. *H*, Haversian canal. The intercellular substance is represented by the uncolored areas between the oval black area and their branches.

3. *Muscular Tissues.*—Muscle cells are recognized apart from all other cells in the frog by the specialization that has taken place in the cytoplasm. As is well known, muscles are divided into voluntary and involuntary. The cytoplasm in the cells of each kind becomes modified so that there results a rapid contraction in the voluntary and a slow contraction in the involuntary muscles. The involuntary

muscle cell has undergone but a small amount of change (Fig. 29); while the voluntary cell is greatly elongated, has special bodies which give a cross-striated appearance and there is more than one nucleus for each cell (Fig. 30). The term sarcoplasm is given to the cytoplasm of muscle cells. Muscular tissues are also sharply distinguished from all other tissues by their function. Muscle cells work by shortening and correspondingly increasing their diameter. This property of contraction is an intensification of the fundamental power of movement in protoplasm.

4. *Nervous Tissues.*—Nervous tissue serves to conduct stimuli and as such must connect the sensory surfaces with the central nervous system, and also the muscles with the coördinating center. The cell elements are ganglion cells and their nerve fibers. The ganglion cells are confined to the central nervous system or to small ganglia just outside this system. The nerve fibers are naked and sheathed. (Discussed in detail in Chapter VI.)

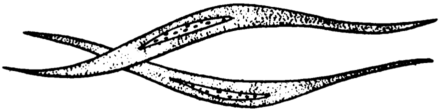


FIG. 29.—Involuntary muscle cells from the stomach of frog.

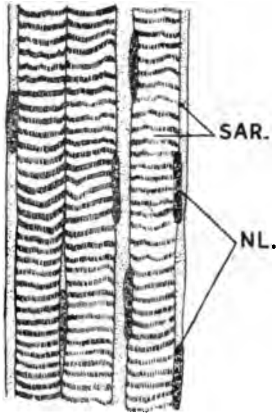


FIG. 30.—Voluntary muscle cells from the fish Amia calva. Notice the narrow layer of unmodified cytoplasm. *NL*, nucleus; *SAR*, sarcoplasm.

The Cell.—All tissues are defined in terms of the cell which is the smallest unit of structure in biology. While the cell is very small, it is perplexingly complex. In the last analysis most of the biological problems are problems of the cells and for this reason a clear understanding of its parts is necessary. The histological study of the intestine as well as Figs. 23 to 30 show that cells vary widely in shape. In some instances the shape is obviously the result of the pressure brought to bear upon the tissue as in columnar cells; while in others there is a widely branching condition which suggests that the shape may be influenced by the nature of the tissue. The spherical ovum is probably the typical shape for a cell and is regarded as the most primitive form of cell (Fig. 44). The parts of a cell may be described by taking a typical cell in the non-dividing stage. This stage is frequently referred to as the "resting stage" but a cell is always metabolically active and irregularly reproductively active, so that the term resting stage as applied to a cell is misleading. The term cell was coined by Robert Hooke in 1665. While working on the vegetal tissue cork he reported that it was composed of "little boxes or cells distinct from one another." What he saw was but the outer limiting membrane, all of the living substance being absent in cork.

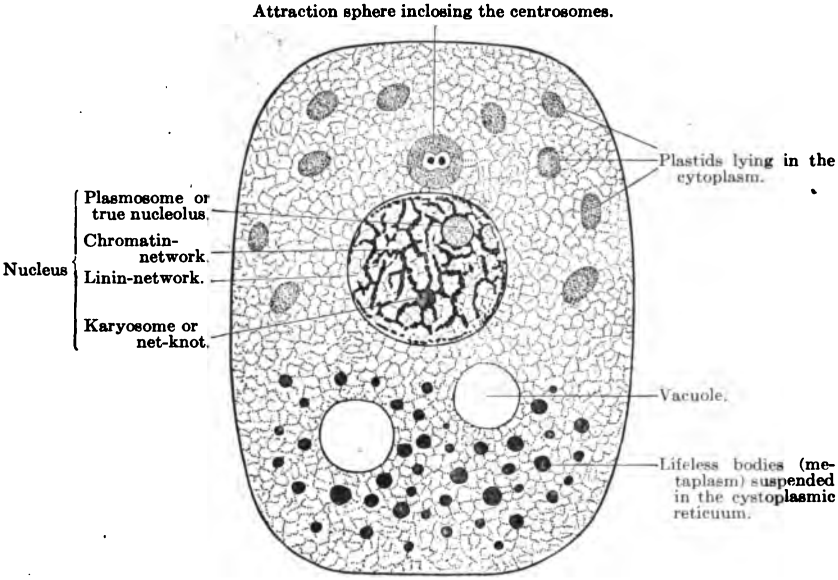

Attraction sphere inclosing the centrosomes.
Plastids lying in the cytoplasm.
Nucleus
Plasmosome or true nucleolus.
Chromatin-network.
Linin-network.
Karyosome or net-knot.
Vacuole.
Lifeless bodies (metaplasm) suspended in the cystoplasmic reticuum.

FIG. 31.—Diagram of a cell. (After Wilson.)

Cell Theory.—In 1838 appeared the memorable contribution of Schleiden and Schwann, who declared as a result of their researches that every plant and animal was composed of cells. Many other investigators verified their conclusions until now their names are always associated with one of the few great generalizations in biology, the cell theory of Schleiden and Schwann. This doctrine implies three propositions: (1) That all organisms can structurally be resolved into cell units, no matter how complex or how simple; (2) that every organism begins life as a single cell which by growth and differentiation gradually assumes the adult form; (3) that the functions or work of all organisms can be interpreted in terms of the activity of its individual cells. "No other biological generalization," says Professor Wilson, "save only the theory of organic evolution, has brought so many apparently diverse phenomena under a common point of view, or has accomplished more for the unification of knowledge." The living substance within the cell was named *protoplasm* by Hugo von Mohl (1846), although the term was earlier used by Purkinje (1840) to designate the formative material of young embryos. Leydig and Max Schultze about 1860 defined a cell as "*a mass of protoplasm containing a nucleus.*"

Protoplasm.—The protoplasm of a cell consists of (1) a *nucleus* (Fig. 31), first described by Fontana in 1871, and regarded as a normal element of the cell by Robert Brown in 1883; (2) the *cytoplasm,* a term formulated by Kölliker in 1863, which by usage has come to be applied to the living substance of the cell-body other than the nuclear, although this was not its first meaning; (3) the usual presence of a cell membrane. The nucleus is usually of rounded form and embedded in the cytoplasm. There is a definite nuclear membrane in most instances when the nucleus is not dividing. Within the nucleus there are two classes of bodies: (*a*) A chromatin network; (*b*) achromatic substances. The one or more rounded nucleoli belong to the first class. The cytoplasm presents a variety of appearances largely depending upon the kind of cell being studied and the stains employed. It is to be regarded as a chemical mixture in which the elements assume various forms. The nucleus and cytoplasm constitute a unit of structure. The subject of cells will receive more extended consideration in the section of this book devoted to the Biology of Cells.

The discovery of the cell and the proper emphasis of the importance of protoplasm to vital processes brings the historic development of biology down to modern times. The remaining discussions of biological phenomena in this book will start from the cell, the modern point of view.

CHAPTER VI.

NERVOUS SYSTEM OF THE FROG.

Nervous System.—The nervous system is composed of three well-known divisions, the central, peripheral, and sympathetic. The central consists of the brain and spinal cord which is protected by the skull and vertebræ and two membranes, the dura and pia mater. To the peripheral division belong all of the nerves arising from the brain, termed the cranial nerves and the spinal nerves. These nerves pass to the skin, sense organs, and muscles. There are two main trunks of the sympathetic system which lie just beneath the spinal column in the coelomic cavity. As these branches cross the spinal nerves there is formed a connection with a slight ganglionic enlargement (Fig. 32). The sympathetic nerves branch profusely in connection with the viscera, forming several plexuses (solar, urinogenital, etc.). The brain and spinal cord form the most important of these three divisions, for to it all general stimulations report and from it all commands are issued.

The gross study of this region reveals a short and somewhat flattened spinal cord with two swellings; the first opposite the arms and the second opposite the hip-region. Fig. 32 explains why these two regions are enlarged; from each large nerves pass off. Posteriorly the spinal cord ends in a small point (the filum terminale). Anteriorly the spinal cord merges into the brain without any sharp demarcation. The brain is subdivided into the following, beginning from behind: the medulla oblongata, the cerebellum, the mid-brain, the thalamencephalon, the cerebral hemispheres and olfactory lobes (Figs. 33 and 34).

The medulla is recognized by the large opening on the dorsal side, the fourth ventricle. This opening is roofed by a non-nervous tissue richly supplied with bloodvessels and termed the posterior choroid plexus (*mtplx.*, Fig. 33). From the sides of the medulla arise five pairs of cranial nerves and from its floor two pairs of eye-muscle nerves. The nerves from this short and insignificant appearing section of the brain regulate the heart in part, respiration, taste, hearing and the general muscles and special senses of the head other than seeing. Immediately

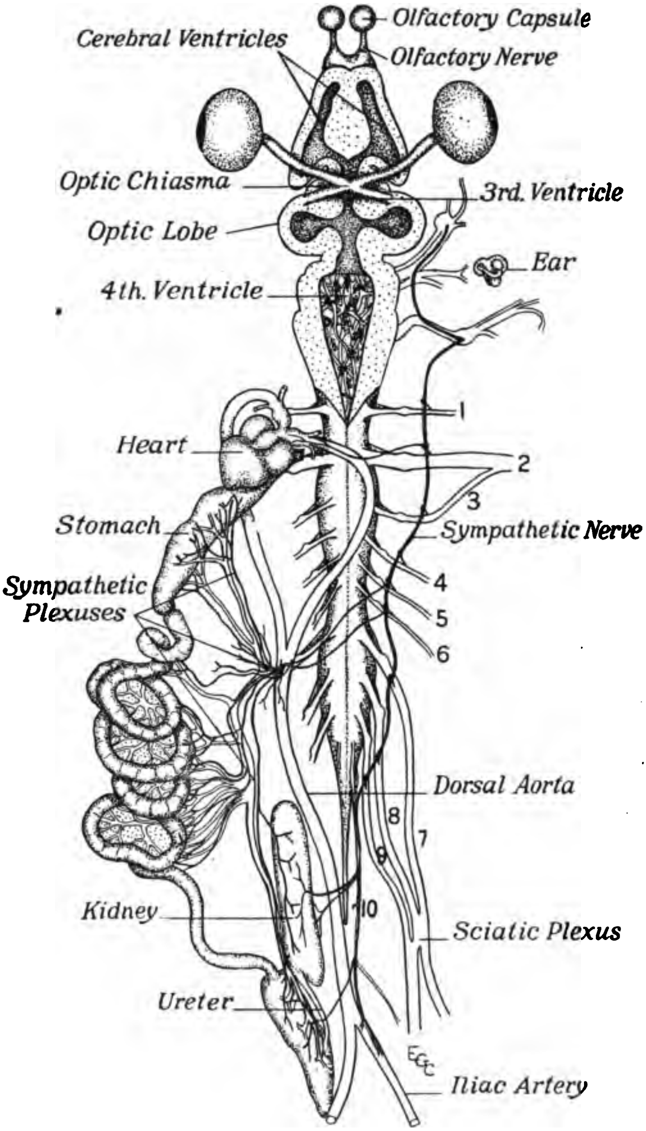


FIG. 32.—Ventral view of nervous system of the toad. The sympathetic nervous system is drawn in solid black lines. Note its relation to the spinal nerves and visceral organs. The floor of the brain has been removed so as to show the ventricles of the brain. Observe the relation that each of the sense organs has to the brain. The eighth nerve is connected with the ear which is closer to the brain than in the drawing.

in front of the medulla is the small transverse fold, the cerebellum, which becomes much larger in the higher vertebrates. The roots of one pair of eye-muscle nerves are located in it. The dorsal surface of the mid-brain is made prominent by the large oval masses (the optic lobes rudimentary in *Necturus*, Fig. 33). The shortest and most inconspicuous section of the brain is the thalamencephalon. Its roof is non-nervous and contains numerous bloodvessels, and hence the term anterior choroid plexus is appropriate (*splx.*, Fig. 33). From the roof arises the pineal body (*epiph.*, Fig. 33), the remnant of a median eye. On the floor of this region is located the prominent crossing

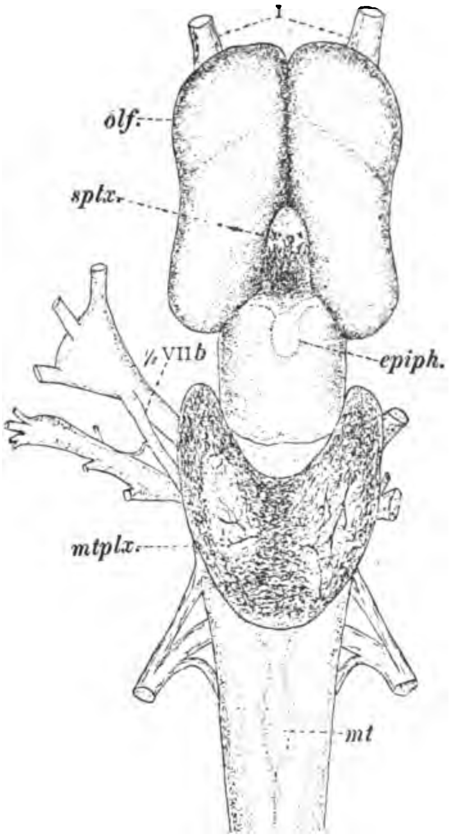


FIG. 33.—The brain of *Necturus maculatus*, dorsal aspect. × 5.4. *olf.*, olfactory portion of cerebral hemisphere; *splx.*, supraplexus; *epiph.*, epiphysis; *mtplx.*, metaplexus; *mt*, metatela. (Kingsbury.)

of the optic nerves (*II*, Fig. 34) called the optic chiasma. Posterior to the optic chiasma is seen a tubular enlargement, the infundibular lobe, partly nervous and partly glandular (*infd.* and *hyph.*, Fig. 34). This small structure of the brain bears a most important relation to normal growth and certain diseases. The cerebral hemispheres are elongated bodies, tapering anteriorly. Near the anterior end a slight constriction marks the division between the cerebral and olfactory regions. It should be noticed that the olfactory lobes lie anterior and not beneath the cerebral lobes as in higher vertebrates. The cerebral lobes are entirely isolated from the sense organs and the

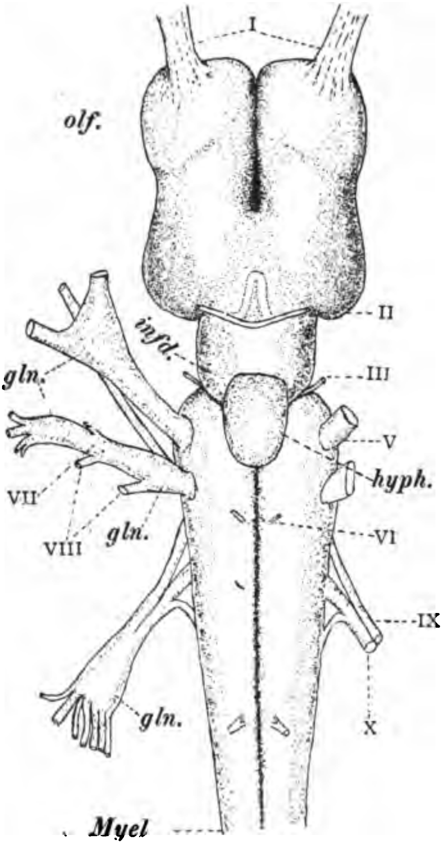


FIG. 34.—Brain of *Necturus maculatus*, ventral aspect. × 5.4. *gln.*, ganglion; *hyph.*, hypophysis; *infd.*, infundibulum; *Myel*, spinal cord; *olf.*, olfactory portion of cerebral hemisphere; *I* to *X*, cranial nerves. (Kingsbury.)

organs of the body. No nerves enter or leave them. Therefore all nerve impulses must first pass through some other region of the brain and all commands issuing from the cerebrum must pass through a second region of the brain before reaching their destination. There is no way of measuring the influence that these associated regions of the brain may have upon the nerve impulses that start from the cerebral hemispheres. This important fact is equally as true for man as for the frog. The distribution of the several cranial and spinal nerves and the sympathetic system should be determined in the laboratory. Compare Figs. 32 to 34.

Tissues of the Central Nervous System.—The nervous system is composed of three distinct tissues, two of which play a minor, although essential, part in the work of the whole system. These minor tissues are the connective and blood; the former supply the protective sheaths and supporting framework, while the latter carry food to all parts and remove the wastes of metabolism. While these two tissues are everywhere present, yet they occupy but a relatively small part of the nervous system. The third tissue is the nervous which represents the most highly specialized cells found in any tissue. Pure nerve tissue such as exists for epithelium is not found in the frog, for the nerve cells rarely join and always have in the frog protective and connective cells that bind them together. Again, a pure nerve tissue would be of no service to the frog unless the nerves were connected with the skin, muscles, etc.

Neuron.—In order to understand the histology of any region of the central nervous system, the nerve cell must be studied.

- Neuron
  - Cell body
    - Cytoplasm
      - Processes
        - Dendrites
        - Neurite, axon or axis-cylinder
    - Nucleus

This diagram and Fig. 35 will help to make clear the several parts in this cell which has become so highly specialized. The term neuron is given to the entire nerve cell, which is to be regarded as a unit of structure. The cell body is much like other cells, varying in shape and size, but has in addition outgrowths from the cytoplasm which are given the general name of processes and are divided into two kinds, dendrite and neurite. It is the processes that indicate the extent of specialization that has taken place in nervous tissue as compared, for example, with epithelial tissue. The large cells in the ventral region of the gray substance of the spinal cord as seen in the laboratory have

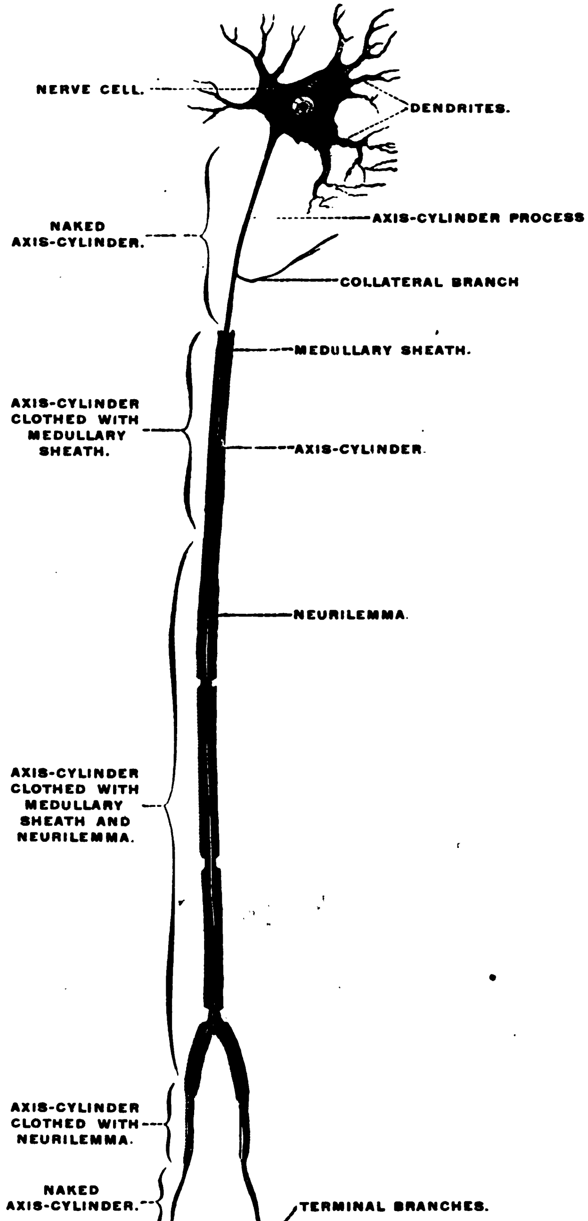


FIG. 35.—Schema of a neuron. All of the parts in this diagram of a neuron belong to a single nerve cell. The structure termed neurilemma is not a part of the neuron in origin. Not all nerve cells are as complex as this one. (After Verworn.

several short processes that are branches, these are the dendritic processes (Fig. 35). Each of these cells is somewhat conical and from the point a slender non-branching process arises which can be traced but a short distance, this is the neurite or axon. By the use of special nerve stains, the axon of these cells can be traced out into the nerve roots that arise from the ventral region of the cord. This axon continues in the nerve to end finally in some muscle. Thus the axons that pass to the hind feet might be six inches long in a large frog, which would make the total bulk of the axon many times that of the cell body which produced it.

Origin of Axon.—The nerve cells arise in the embryo as rather regular columnar epithelial cells with an entire absence of processes. As the embryo frog develops, small outgrowths arise on the cells that are to become neurons. These continue to grow, deriving their growing energy from the cell body. As they first arise they are naked processes, many of which remain as such throughout the life of the frog; but part of them become surrounded by well-defined, thick, fatty sheaths, the medullary sheaths, which are secreted by the axons which are thus enveloped (Fig. 35).

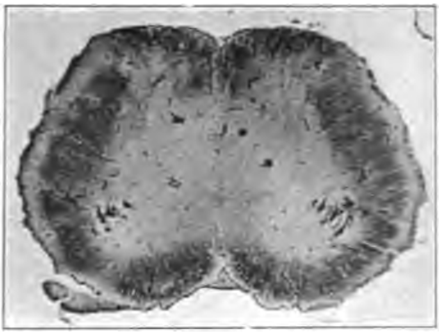


FIG. 36.—Photomicrograph of spinal cord of *Rana pipiens*. The motor nerve cells are stained black.

Histology of the Spinal Cord.—An analysis of the finer structure of the spinal cord will serve to illustrate the complexity of this highly specialized organ and give some insight into the way it works. The whole spinal cord is enclosed in a strongly protective membrane, the pia mater. Within the pia mater the cord is constricted on the dorsal and ventral surfaces. These constrictions are the dorsal and ventral sulci (posterior and anterior fissures of human anatomy). The area of the cord, when seen cut in cross-section, is made up of a peripheral layer of white substance in a fresh section, the white appearance being due to the fat in the medullary sheaths of the axons in this region, and of the central area of gray substance. In the region where the spinal nerves arise the gray substance extends in strands to the surface of the cord. This gives to the gray substance much the shape of an expanded butterfly. The white substance of the cord is occupied mostly by medullated nerves running longitudinally; while the gray substance is composed of numerous nerve cells and their unsheated processes. The center of the gray substance is occupied by a small cavity, the neurocele, which is surrounded by epithelial cells, the bases of which can be traced far out into the substance of the cord. This central nervous cavity extends throughout the length of the central nervous system and becomes expanded in the brain into the four ventricles (Fig. 32). At certain definite places the nerve fibers in the cord cross (Fig. 37). Here and there in any section of the spinal cord bits of capillaries show with their contained blood corpuscles.

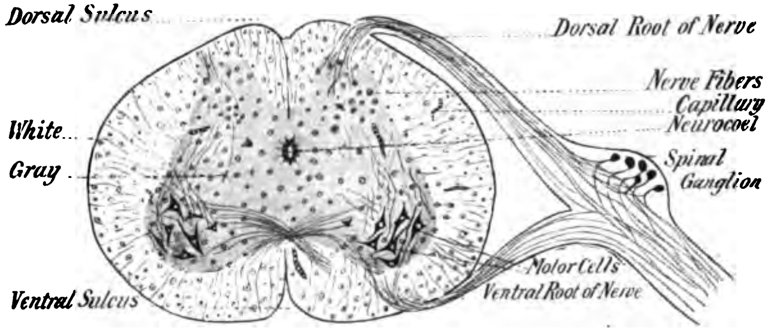


FIG. 37.—Diagram of spinal cord of frog.

Nerves.—Between the segments of the spinal column, pairs of spinal nerves pass off from the cord. Each nerve arises by two roots from the cord; one from the dorsal region, and one from the ventral. On the dorsal root there is a small enlargement that contains many cell bodies which give origin to nerve processes. The presence of these nerve cells on the dorsal root distinguishes the two roots as to form as well as to function. The ventral root is mostly made up of fibers which grow out from the large cells in the ventral region of the gray substance and the most of them end in some muscle. This means that the nerve stimulus travels outward and away from the spinal cord over these fibers. This also means that these fibers cannot be stimulated normally except through the spinal cord. The term motor or efferent is given to the ventral root. The dorsal root consists exclusively of fibers which arise from the cells in the dorsal ganglion. Part of these fibers pass out into a nerve and are enclosed in the same general sheath with those from the ventral root for a part of the way. The dorsal root fibers end in the skin. From the same dorsal ganglion cells fibers grow into the spinal cord and send branches in several well-known directions. The normal stimulus for the dorsal root fibers is something that reacts on the fiber ending in the skin. Such a nerve impulse is carried to the spinal cord where it is interpreted usually through the assistance of the brain; and the resulting explanation is sent out over the motor fibers to the muscles. The dorsal root, then, is known as the sensory or afferent root. Such is the structural plan of each spinal nerve. The nerves that arise from the brain have lost some of their primitive parts and each must be studied separately. Within the central nervous system there are many definite paths over which certain nerve impulses travel, but their study belongs to a course in neurology.

Stimulation of Nerves.—The most conspicuous feature of the nervous system is its power of responding to light, heat, touch, sound, etc., that is, to a stimulus. This power of being aware of the various stimuli is based upon a fundamental characteristic of protoplasm known in biology by the name of irritability. Originally all of the cells possessed this property but as they grew into bone, muscle, etc., there was no need for irritability and it remained undeveloped. But irritability is only part of the work of responding to a stimulus, the light or heat stimulus is conducted along the nerves to the central nervous system. Here it is interpreted and the frog acts according to the nature of the stimulus. For the frog to respond to a stimulus involves the use of three highly developed fundamental protoplasmic properties, *i. e.*, irritability, conductivity, and coördination. These three processes, then, are at work in every nervous response of the frog.

Organic Movement.—The power to make a definite kind of movement was characterized in the first chapter as an exclusive property of living things. The kind of movement meant was such as grows out of the complex series of interacting stimulations that follow. The frog may be assumed to see a man approaching, the sight stimulation is carried to the brain and there are sent out impulses to the muscles which result in a series of movements so directed that the frog is able to jump into the water and swim away from shore. In these simple reactions there is one fact of great importance when these changes are contrasted with inorganic movement, that is, that the frog can change the direction in which he is moving. It makes very little difference how this fundamental characteristic of living matter is named; it may be called movement, coördination or response to a stimulus (having the property of irritability). The fact remains that it is universal in all higher animals. In the study of paramecium, a single-celled animal, similar relations exist. The tendency for the higher plants to remain stationary has resulted in the elimination of this property. Movement in its simplest expression is regarded as regulated by the nervous system without the intervention of the brain. The stimulation comes from the skin and is reflected by the cord to the muscles; and so the term reflex action is employed to describe the simple forms of movement.

LORSAR, WM.: A Study of the Function of Different Parts of the Frog's Brain, Jour. Comp. Neurol., 1905, vol. xv.

WYMAN, A.: Anatomy of the Nervous System of Rana Pipiens, Smithsonian Contribution to Knowledge, 1853, vol. v.

CHAPTER VII.

EMBRYOLOGY.

Somatic and Germ Cells.—Until one has actually seen the single-celled ovum change into many cells, elongate, and become a tadpole and finally a frog, the statement that such is the sequence of events seems incredible. In selecting the frog to illustrate the principle of growth and the origin of a new organism in Nature, for the two are continuous and inseparable processes, the purpose is to consider it in its broader aspects. The parent frogs possess either spermaries in which are produced sperms or ovaries that grow many ova. Both sperms and ova are free cells and do not unite to form tissues like

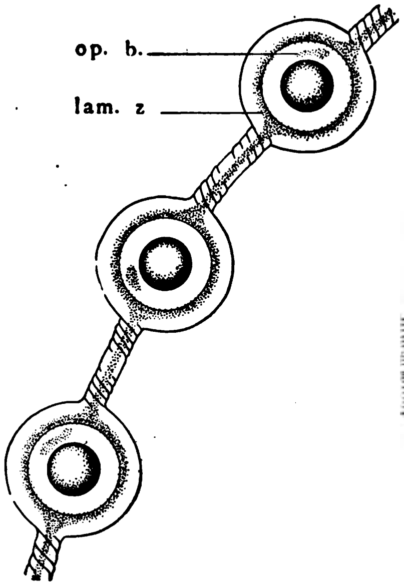


FIG. 38.—Eggs and egg envelopes of *Cryptobranchus*, natural size. *op. b.*, opaque body; *lam. z.*, lamellar zone of the envelope. (B. G. Smith, in Journal of Morphology.)

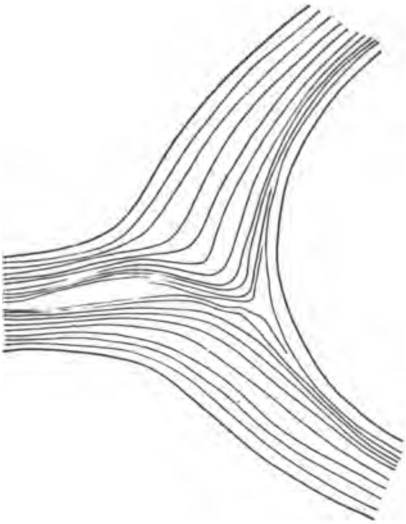


FIG. 39.—Optical longitudinal section through the lamellar zone of the envelope in the region of the junction of the egg capsule with the connecting cord. × 13. (B. G. Smith, in Journal of Morphology.)

epithelium or muscle. This free state is a primitive condition and if these cells had some physiological work like digestion to perform, they would be inefficient. But early in the life of the frog the cells which are to be responsible for growing sperms and ova are set apart and never develop into highly specialized adult tissue cells. This gives in each frog one class of cells that continue to grow, eventually becoming highly differentiated. During this growth the cells are specialized and united into definite tissues which in turn are distributed into complex organs. After such cells have become thus specialized, they lose their power to grow new cells other than those

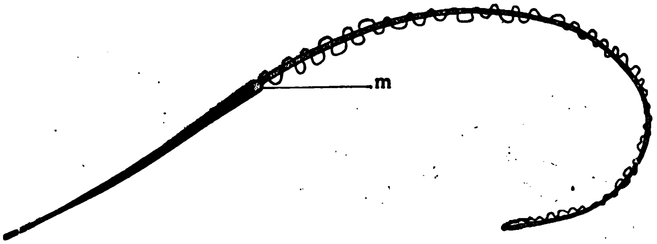


Fig. 40.—This highly specialized cell develops from one that has a nucleus, surrounded by cytoplasm. The conical, dark body is the sperm head and corresponds to the chromatin of the nucleus. The portion with the wavy margin is the tail and is all that remains of the cytoplasm. Spermatozoön. *m*, middle piece. × 500. (B. G. Smith, in Journal of Morphology.)

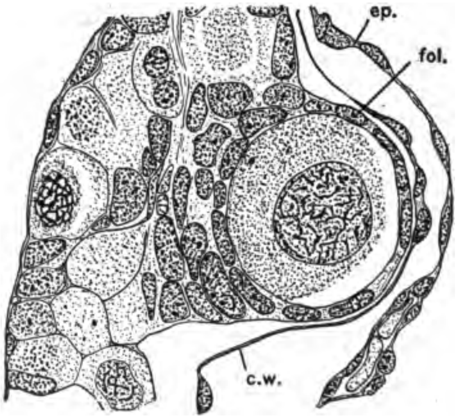


Fig. 41.—The largest cell is the young ovocyte of *Cryptobranchus*. In what particulars is it similar to the other cells in this figure? *ep.*, inner epithelial membrane of the ovarian wall; *fol.*, follicle cell; *c.w.*, cyst wall. (B. G. Smith, in Journal of Morphology.)

like the tissue in which they occur. The term somatic cells is given to all such cells. The sperm and ovum cells are never in their adult form united into tissues and they retain their power to grow new cells. They are called germ cells.

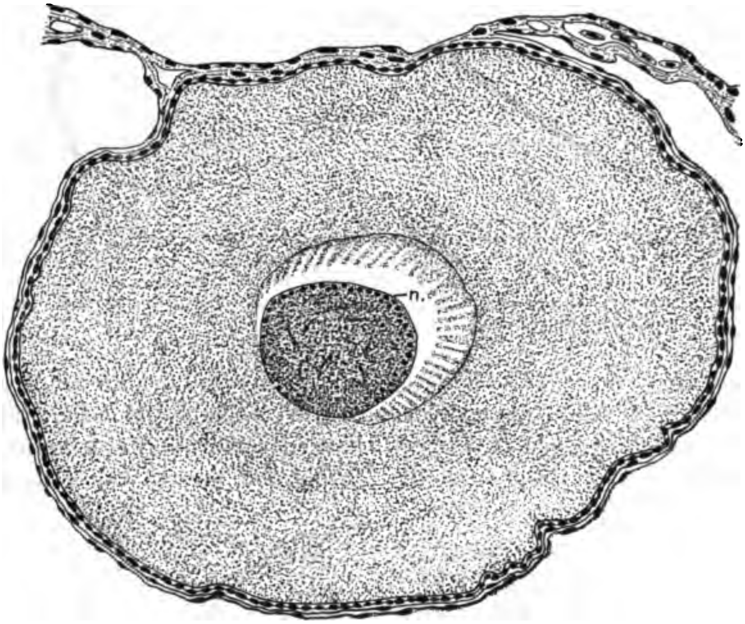


Fig. 42.—Section through an ovocyte and ovarian wall of a 35 cm. *Cryptobranchus*, showing the follicle and the distribution of nucleoli. Compare this stage with Fig. 41. (B. G. Smith, in Journal of Morphology.)

Ova and Sperm Cells.—The ovum of the frog is not a typical germ cell because the cytoplasm is packed full of stored-up food, known as deutoplasm (Fig. 43). The result is that most of the cytoplasm and the nucleus are crowded into one region of the ovum. Associated with this concentration of cytoplasm is a black pigment. This pigmented region is called the animal pole of the ovum, and the opposite region, the vegetal pole. The pigmented area is always uppermost and directed toward the sun because the animal pole is of less specific gravity than the vegetal region.

The highly specialized ovum of the frog represents a cell that started out with a central nucleus surrounded by cytoplasm. During the growth of the young ovum which is usually termed an ovocyte there is deposited in the cytoplasm the deutoplasm. Deutoplasm is made by the life processes of the ovocyte and is a product of constructive metabolism. This means that the inert deutoplasm of the frog's ovum must have been living ovocyte protoplasm at one stage. Such stored-up energy is used by the developing embryo.

After a study of the ovocyte stages in Figs. 41–43 and the ovum as shown in Fig. 44, explain how the ovocyte is changed from one stage to another. Does the term growth correctly describe these changes? *Define growth in terms of the ovocyte and ovum.*

The sperm cell has departed from the rounded primitive shape for cells and has assumed a highly specialized form. The cytoplasm has become reduced to a very small amount and forms the tail, while the nucleus is concentrated into a solid mass of chromatin, the sperm head. The long vibratile tail assists in the movement necessary to bring the sperm cell to the ovum (Fig. 40).

When the eggs are first extruded, they are surrounded by a thin mass of gelatinous substance secreted by the cells in the wall of the oviduct. This may be briefly referred to as jelly. Within one minute after the egg is laid, the jelly begins to absorb water. In from ten to fifteen minutes it becomes about six times as thick as when first brought in contact with the water. As this thickening takes place definite layers can be made out in it (Fig. 39). The jelly serves to unite the eggs in a mass, to protect them from mechanical injury

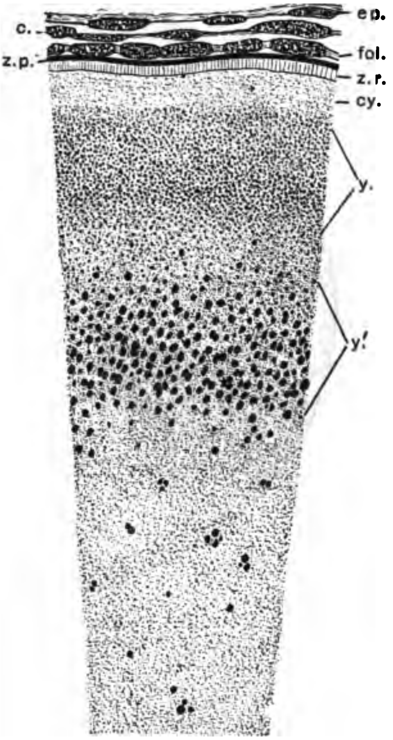


Fig. 43.—Portion of a section through one of the most advanced ovocytes of a 35 cm. *Cryptobranchus*, showing the structure of the membranes surrounding the egg and the early formation and distribution of yolk granules (deutoplasm). × 340. *c.*, cyst membrane; *cy.*, yolk-free peripheral zone of cytoplasm; *ep.*, inner epithelial membrane of the ovarian wall; *fol.*, follicular membrane proper; *z.p.*, zona pellucida; *z.r.*, zona radiata; *y.* and *y.'* layers of fine and coarse granules respectively. (B. G. Smith, in Journal of Morphology.)

and to prevent them from being eaten by microscopic animals. The ova are numerous spherical bodies about 1.75 mm. in diameter.

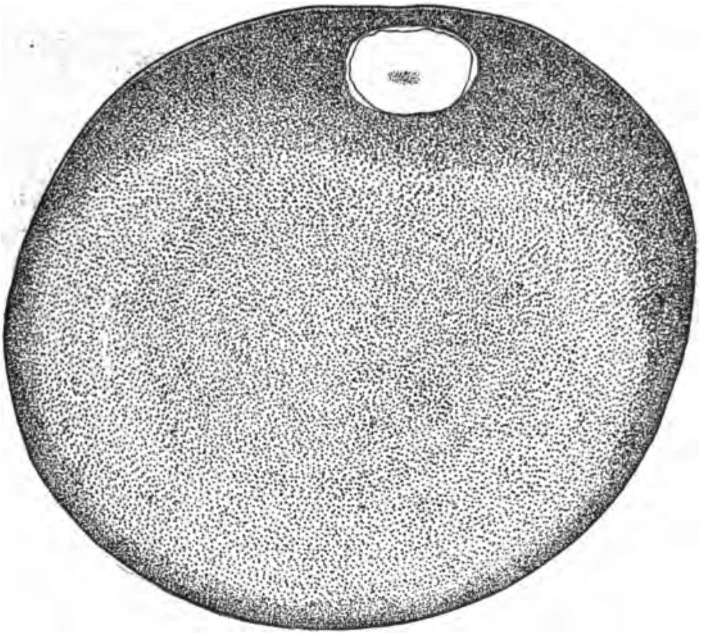


Fig. 44.—Ovarian egg of adult *Cryptobranchus*. How does this egg differ from the ovocyte? (B. G. Smith, in Journal of Morphology.)

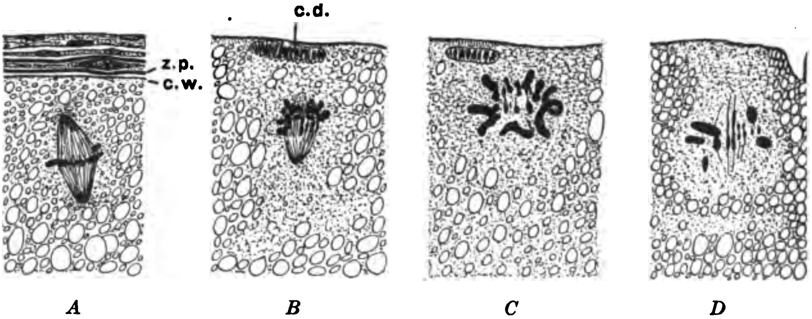


Fig. 45.—Showing first polar spindle of *Cryptobranchus*. *c.d.*, contact disk; *c.w.*, cell wall formed from the zona radiata; *z.p.*, zona pellucida. In *C* the section cuts the spindle obliquely and includes all the chromatin except one small chromosome belonging to the central part of the group, which is left in an adjacent section. There are probably six large chromosomes forming a ring surrounding six small chromosomes in a state of division. The chromosomes are the black bodies. (B. G. Smith, in Journal of Morphology.)

Black in color, they readily absorb heat. The sperms and ova may be frozen without being destroyed, if the exposure is short.

Rana catesbiana breeds from June 15 to August 1. The large egg-mass is laid in a short time. The egg-mass has a pancake-like shape from one to three feet across, and in it are found from 12,000 to 20,000 eggs which hatch in three to five days.

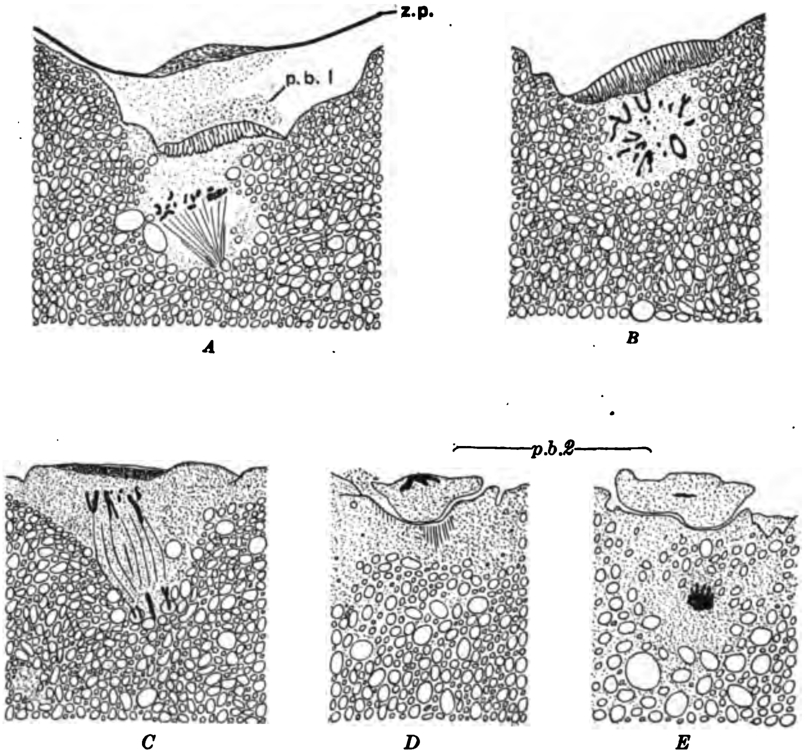


FIG. 46.—Sections showing the second polar spindle, and the formation of the second polar body and egg nucleus in *Cryptobranchus*. *z.p.*, zona pellucida; *p.b. 1*, debris of the degenerating first polar body; *C*, late anaphase, second polar spindle; *D* shows second polar body, *p.b.2*; *E* has the newly formed egg nucleus. (B. G. Smith, in Journal of Morphology.)

Maturation.—The term maturation is used to describe several important changes that take place in the full-sized egg before fertilization is possible. These changes are mainly limited to the nucleus. The nucleus of the ovum contains too much chromatin and the excess must be removed and forced through the cell wall (vitelline membrane). The process of getting rid of the chromatin consists of a series of detailed changes that are well illustrated in Figs. 45 and 46. In this process there are two general features that may be emphasized: (1) The changes in the chromatin; (2) the method by which the chromatin is removed. The conditions diagrammed in Figs. 49–52 illustrate the usual method by means of which the cell divides. It is called the mitotic or indirect method of cell division.

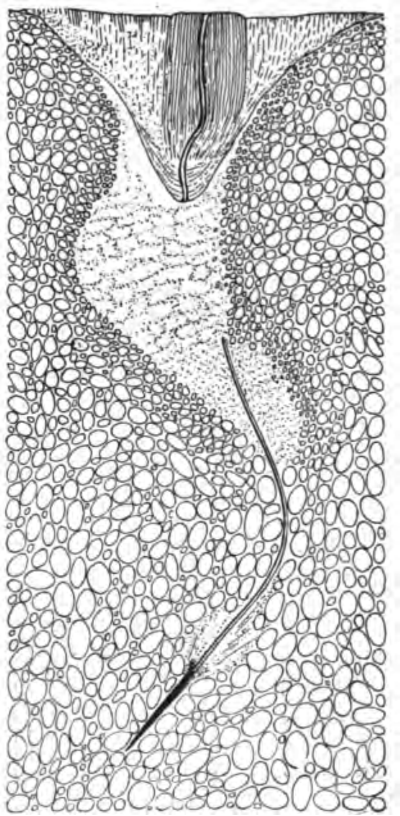


FIG. 47.—Vertical sections of egg of *Cryptobranchus*, showing penetration of the egg by a spermatozoön. × 240. Two and one-half hours after fertilization. (B. G. Smith, in Journal of Morphology.)

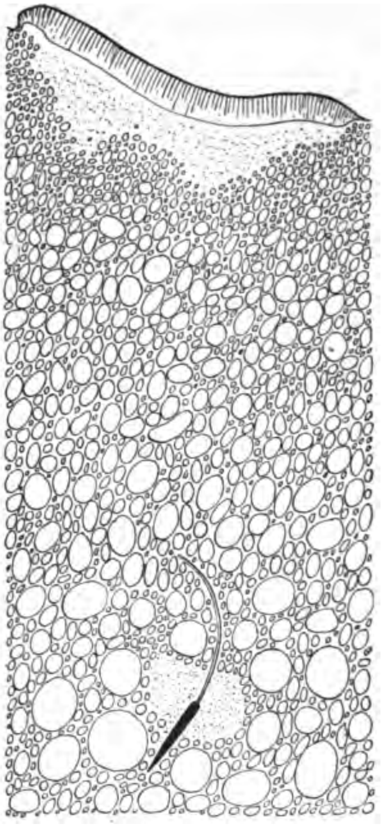


FIG. 48.—Same as Fig. 46, three hours after fertilization. (B. G. Smith, in Journal of Morphology.)

The mechanism for the removal of the excess of chromatin consists in the formation of a temporary structure in the cytoplasm, the spindle. The exact origin of all of its parts is still a subject of controversy, and they are not the same in all animals. The conditions in the frog are about the same as shown in the illustration for *Cryptobranchus*. A spindle arises in the cytoplasm close to the egg nucleus, it is made up of fibers which extend from pole to pole of the spindle as well as fibers which radiate around each pole, these latter are known as the astral fibers (Figs. 49 and 52). The astral fibers terminate in a deeply staining body known as the centrosome. As the spindle grows some of the fibers push their way through the weakening nuclear membrane and come in contact with certain chromatic masses that have become larger during the time that the spindle was forming in the cytoplasm (Fig. 49, *IV*). These particular chromatin masses continue to enlarge and become organized into a definite number of discrete chromatin bodies which are now termed chromosomes. The number in the common toad is 12, in *Rana temporaria* 10, and in *Cryptobranchus* 12, and they are constant for each species.

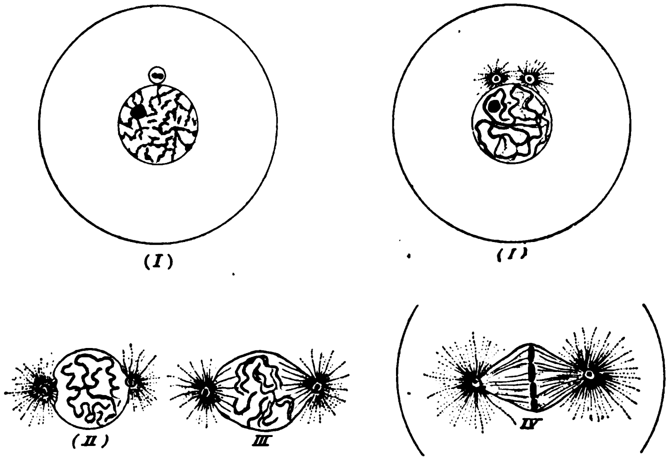


Fig. 49.—Prophases of karyokinesis. *I*, division and migration of centrosome; *II*, resolution of chromatin into well-defined thread; *III*, segmentation of same into chromosomes; *IV*, development of amphiasters; chromosomes equatorial. (Wilson.)

The chromosomes are drawn into the spindle until they are arranged symmetrically midway between the two poles of the spindle. The growth of the spindle and the increase in size and arrangement of the chromosomes between the poles of the spindle is a preparatory process and is named the prophase stage. The number of chromosomes and the amount of chromatin is the same in each species.

As soon as the chromosomes take the equatorial position and divide (Fig. 49, *IV*), it is customary to use the term metaphase in describing this second stage. In a short time the chromosomes divide, each chromosome splitting into two equivalent parts which move toward each pole of the spindle (Fig. 46, *C* and 51). One pole of the spindle moves to the periphery of the ovum, and by the constriction of a small portion of the cytoplasm this distal pole of the spindle and the chromosomes associated with it are cut off from the rest of the ovum (Fig. 46, *A, p.b. 1*). The obvious result is that one-half of the original amount of the chromatin in the nucleus has been removed from the ovum.

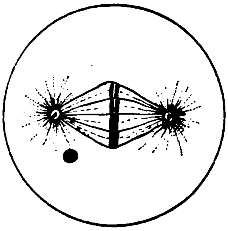


FIG. 50.—Metaphase of karyokinesis. (Wilson.)

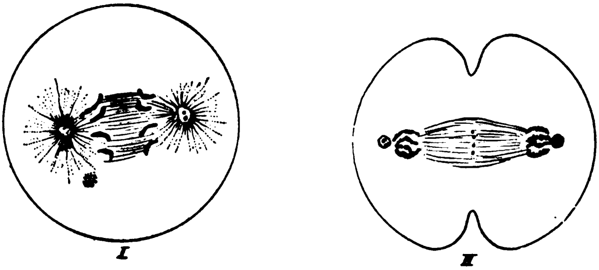


FIG. 51.—Anaphases of karyokinesis. (Wilson.)

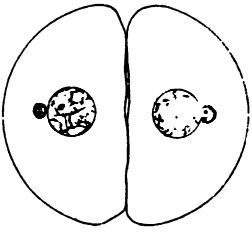


FIG. 52.—Telophase of karyokinesis. (Wilson.)

The parts thus removed by this process constitute the first polar cell. The portion of the spindle remaining in the cytoplasm, except the centrosome, dissolves and is transformed into the cytoplasm. A new spindle arises now under the direction of the old centrosome that remained in the ovum. The work of the new spindle repeats the process already described and there is produced a second polar cell.

Fig. 53

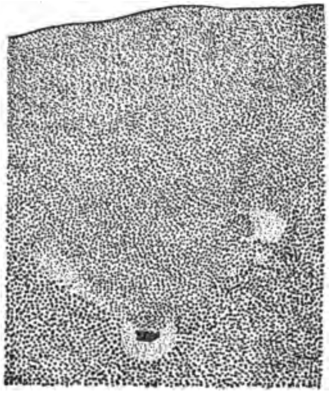


Fig. 54

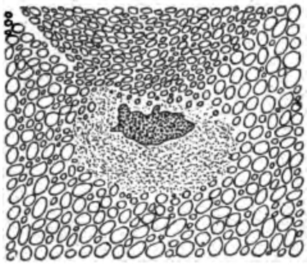
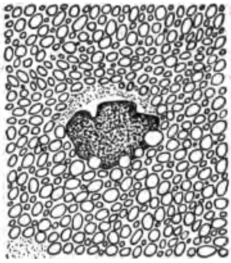


Fig. 55



Figs. 53, 54 and 55.—Fig. 53, an egg killed ten and one-half hours after fertilization, showing the sperm nucleus. The sperm nucleus is enlarged three times as much as in Fig. 54. Fig. 55, section through an egg killed ten and one-half hours after fertilization. (B. G. Smith, in Journal of Morphology.)

At the close of the formation of the second polar cell the remaining chromosomes gradually become transformed into a nucleus but a nucleus that has lost three-fourths of its original amount of chromatin. This process is termed maturation and is preparatory to fertilization. The new nucleus is called the *female pronucleus*, to distinguish it from the nucleus of the ovum (Figs. 56 and 57). The two polar cells soon disintegrate and play no further part in development. The first polar cell is formed and the second polar division has reached the metaphase stage by the time the egg has reached the lower end of the oviduct. The remaining steps in the formation of the second polar cell usually do not take place until after the eggs have been laid and the sperm has entered into the cytoplasm.

Fertilization.—While maturation is thus taking place the sperm enters the ovum (Fig. 47) and is gradually transformed into a nucleus (Figs. 48 and 53–55). This change results through the increase in size of the sperm head, which is nearly all chromatin; it gradually becomes vacuolated and secretes its own nuclear membrane. In appearance this sperm nucleus is like the egg nucleus; while in many instances it is as large, in *Cryptobranchus* it is much smaller (Fig. 58). As a rule one must know the exact history of the two nuclei found in an ovum during fertilization in order to be able to tell their origin, so similar are the two. The male nucleus in the ovum is called the *male pronucleus*

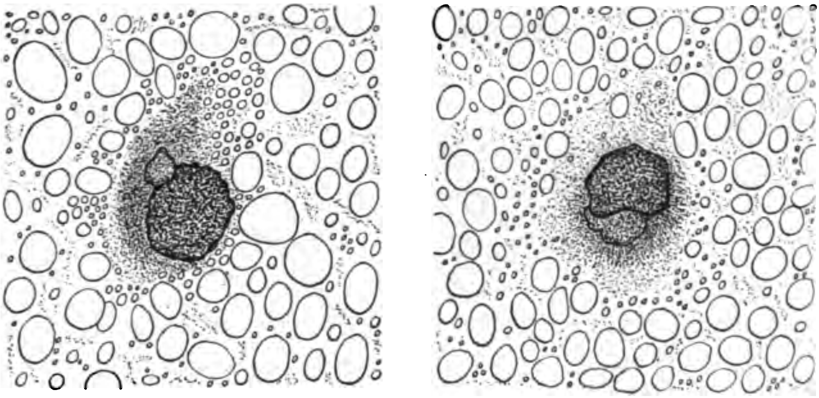


FIG. 56 FIG. 57

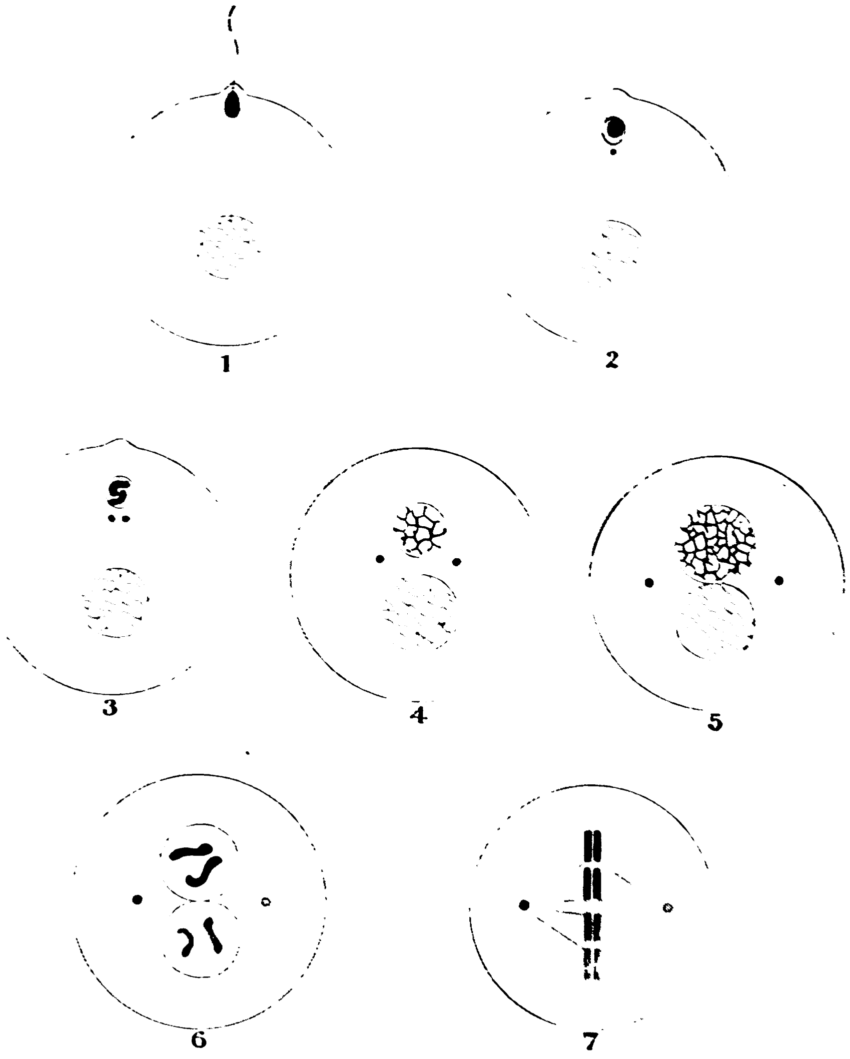
FIGS. 56 and 57.—Sections through eggs killed twelve hours after fertilization, showing the fusion of the male and female pronuclei. The male pronucleus is probably the smaller. (B. G. Smith, in Journal of Morphology.)

As the two pronuclei grow to full size the male pronucleus moves through the cytoplasm until it comes in contact with the female pronucleus (Figs. 56 and 57). At about this time the nuclear membrane of each begins to break down and the contents of the two pronuclei[1] become enclosed in a single, irregular-shaped nucleus.

---

[1] For the discussion of the significance of male and female chromosomes see chapter on Heredity.

PLATE I



Fertilization. (After Adami.)

1. Entry of spermatozoön into ovum. 2. Loss of tail of spermatozoön. 3. Division of centrosome. 4 and 5. Chromatin both of ovum and spermatozoön converted into a network; the two moieties gain approximately equal size. 6. Chromatin of both becomes arranged into chromosomes (one-half of the number of each variety that is usual in the body cells of the species). 7. Formation of spindle; division of chromosomes; partition of chromosomes derived from the two parents in equal number between the two future cells (blastomeres).

This uniting of the two pronuclei is fertilization. Fertilization takes place outside of the body of the frog. It is difficult to state to just what extent the chromosomes of each pronucleus retain their identity and to what extent they fuse. At any rate the number of chromosomes is not increased by fertilization. This new nucleus resulting from the fusion of the male and female pronuclei is termed the *segmentation nucleus* and the ovum is now properly designated as an embryo.

Segmentation.—After maturation and fertilization the egg begins to show signs of segmentation. The time varies with the temperature, being usually two or three hours after fertilization. Segmentation begins as a vertical furrow in the pigmented region (Fig. 58).

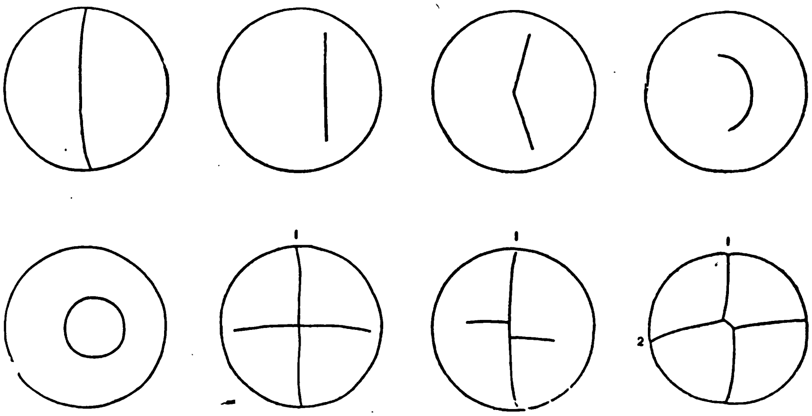


FIG. 58.—Types of first and second cleavage of *Cryptobranchus* as seen at the animal pole. (B. G. Smith, in Journal of Morphology.)

This furrow continues until it surrounds the embryo. A division of the nucleus precedes this cytoplasmic segmentation. The result of this constriction is to cut the embryo into two cells. Where the segmentation divisions pass entirely through the embryo it is said to be total. The second segmentation begins about one hour after the first and in a similar manner, but in a vertical plane at right angles to the first (Fig. 58). The third segmentation in the frog is not just like that shown for *Cryptobranchus* in (Fig. 59), but is in a horizontal plane at right angles to the first two and a little above the equator of the embryo, which results in producing eight cells, four small ones at the animal pole and four large ones at the vegetal pole. The third division of the embryo results in forming four small cells and four large cells. This cleavage is thus unequal. The first division of the frog embryo illustrates what is meant by total *segmentation* or *cleavage* in the embryonic development of an animal; while the third division is described as unequal segmentation. Segmentation takes place from now on more rapidly at the animal pole and in a short time the cells at the vegetal pole are found to be much larger than those at the animal pole (Fig. 61). The rate of division is intimately associated with the quantity of yolk present. There are a number of external changes which can be readily observed.

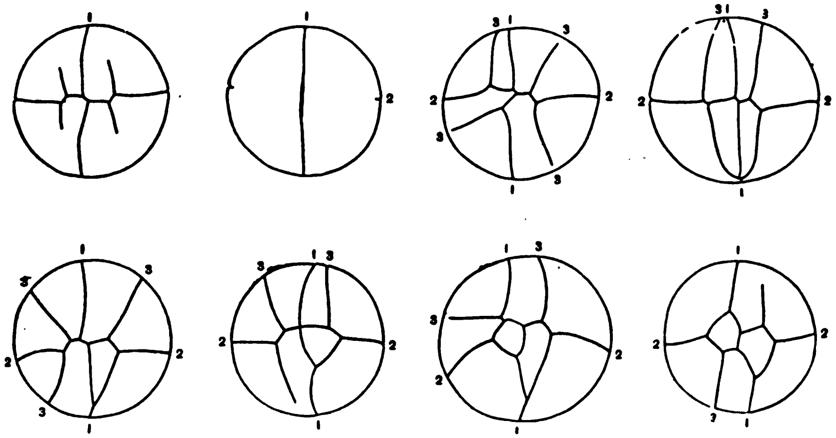


Fig. 59.—Types of third cleavage of *Cryptobranchus*. All the figures are of the upper hemisphere (animal pole) except the second one in the upper row which represents the lower hemisphere of the first egg shown in the upper row. (B. G. Smith, in Journal of Morphology.)

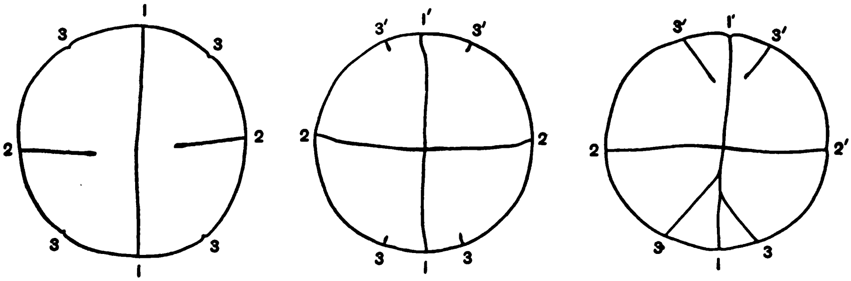


Fig. 60.—Lower hemisphere (vegetal pole) of fourth cleavage stage of *Cryptobranchus*. (B. G. Smith, in Journal of Morphology.)

As the cells at the animal pole continue to grow more rapidly than those at the vegetal pole they soon spread over these large cells. This results in forming a layer of small cells which almost completely surrounds the embryo. The term *germ layer* is given to such a layer of cells. As the development continues, two more germ layers can be recognized. The one on the outer surface is the ectoderm. The primitive digestive canal is lined with the germ layer known as endoderm; while the third layer is the mesoderm. From each of these germ layers the organs of the frog are derived.

The ectoderm gives rise to the skin, nervous system, parts of all of the sense organs, as eyes, ears, etc. The mesoderm forms the muscles, skeleton, blood and bloodvessels, kidneys and reproductive organs. The liver, pancreas and mucosa of the intestinal tract come from the endoderm.

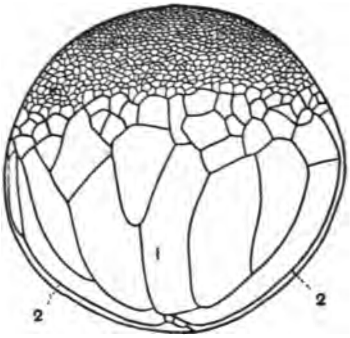


Fig. 61.—Stage nine of the cleavage of *Cryptobranchus*. Equatorial. Note the difference in size of cells at the two poles. (B. G. Smith, in Journal of Morphology.)

For a considerable time the embryo retains its spherical form (Fig. 61). One of the first changes to be noted is a flattening on the dorsal surface (Fig. 62). A groove soon appears in this region which is the neural groove. The edges of the neural groove unite, enclosing a cavity. This union begins at the anterior end, thus forming first the forebrain and more posteriorly the spinal cord, both of which are derived from the ectoderm. During this time the embryo has elongated in a direction which marks the longitudinal axis of the animal. The mouth, anal opening, nostrils, gill-slits, and sucker appear as the embryo elongates.

Tadpole.—It is from four to five days after hatching before the mouth becomes connected with the remainder of the digestive tube, and during this time the tadpole is dependent for food on the unused yolk (Figs. 64 and 65). The tadpole soon attaches itself by means of its sucker to weeds, etc., and breathes by means of three pairs of external gills. Soon after this stage the mouth becomes connected with the digestive tube, the intestine increases greatly in length and becomes much coiled and the tadpole feeds on minute animals. A few days after hatching a fold of skin grows from the side of the head to cover the external gills, leaving a small opening on each side the spiracle, which later closes on the right side, leaving a single spiracular opening on the left side for the exit of water. This fold of skin is the operculum. After the external gills are covered by the operculum

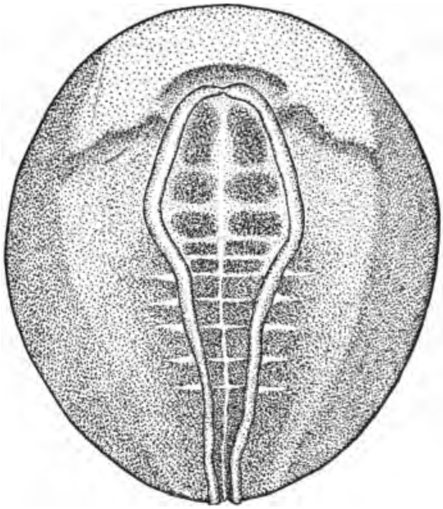


Fig. 62.—Anterodorsal view of a living embryo of *Cryptobranchus*, viewed mainly by transmitted light, showing neural groove. Free-hand sketch. (B. G. Smith, in Journal of Morphology.)

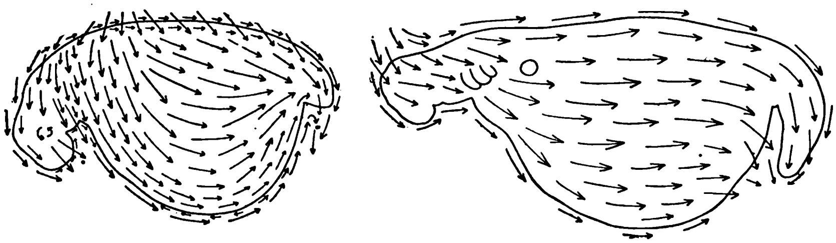


Fig. 63.—Diagrams of embryo of *Cryptobranchus*, showing the direction of the water currents produced by the cilia. (B. G. Smith, in Journal of Morphology.)

Fig. 64

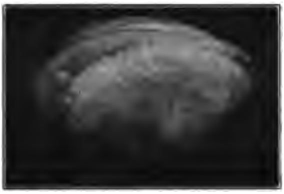


Fig. 65

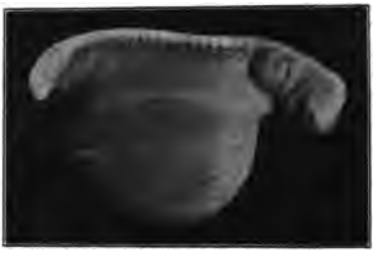
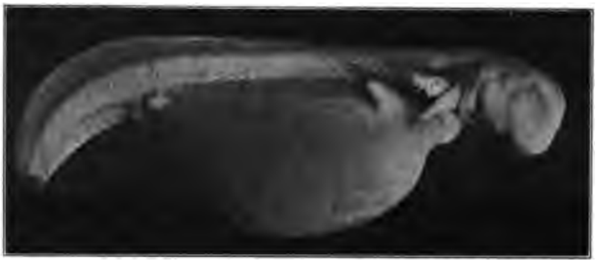


Fig. 66



Figs. 64, 65 and 66.—Embryos of *Cryptobranchus*, showing the gradual formation of the body and the presence of the yolk. (B. G. Smith, in Journal of Morphology.)

Fig. 67

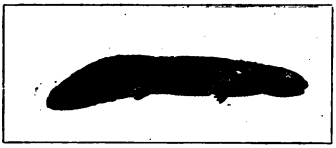


Fig. 68

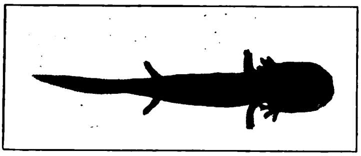
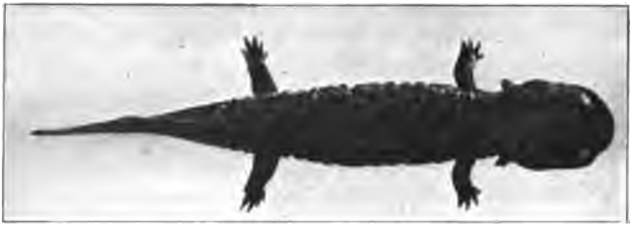


Fig. 69



Figs. 67, 68 and 69.—Fig. 67, larva of *Cryptobranchus* two months after hatching; Fig. 68, ten weeks after hatching; Fig. 69, larva one year old. The newly hatched larva retains a supply of yolk sufficient to last it from two to four months. Pulmonary respiration is established about five months after the hatching period. The metamorphosis takes place at the end of the second year. Sexual maturity is attained, probably at the end of the fourth year. (B. G. Smith, in Journal of Morphology.)

they are gradually absorbed and respiration is accomplished by means of the internal gills, which appear about the time that the mouth opens. Up to this time the tadpole is a fish-like animal with a long vertically flattened tail. The muscle segments show on the side of the tail through the skin. *Rana catesbiana* lives for a year in this stage. During the second summer the hind limbs begin to appear as the tail is gradually absorbed, then the front limbs break through the skin and the tadpole becomes a frog. There are important and interesting internal rearrangements accompanying these external changes. The series of changes by which the tadpole is transformed into a frog is known as *metamorphosis*.

Life Cycle.—The study of the frog began with the adult animal composed of organs, tissues and thousands of cells. In the germ glands eggs or sperms were produced that were set free during the breeding season. These united and an embryo resulted. The embryo underwent a series of segmentation stages which finally resulted in the production of a tadpole. After a time the tadpole transformed into an adult frog. The term life cycle is applied to all of the stages in the life of the frog beginning at any stage and continuing until this stage is reached again. The life cycle of the frog might begin with the adult and include the stages as given at the beginning of this paragraph; or it might begin with the tadpole or any other stage if all of the others are brought into their correct relation to the stage selected.

As the result of this study of the embryology of the frog, write a definition of growth employing the following terms: ovocyte, cleavage, nervous system and tadpole.

BIOLOGY OF UNICELLULAR ORGANISMS.

CHAPTER VIII.

PARAMECIUM—AN ANIMAL MADE UP OF A SINGLE CELL.

Habitat.—The animals whose bodies are composed of a single cell are to be found in definite environmental relations to other animals and plants. The mere fact that they are microscopic in size does not imply that the general conditions surrounding them are different from those of other organisms. The habitat of the frog was found to be in definite relation to water, to the seasons and to food.

Paramecium is found in both salt and fresh water and cannot live in any other medium. It is abundant in the temperate fresh-water ponds and streams, especially if the water is stagnant. It is easily kept in aquaria in the laboratory, if supplied with plenty of bacteria such as are present in a hay-infusion. Paramecium is not found in all fresh water. Ordinary drinking-water does not contain it nor is it found in abundance in flowing streams or large lakes. But in water that contains decaying plants and tends to be stagnant, paramecium is usually present. It is not necessarily present even in this ideal habitat, not being found in such conditions unless paramecia have been living there previously, for these microscopic animals follow the same manner of propagation as the frog; namely, there must be living paramecia to give rise to paramecia. When the food conditions are favorable these animals become very numerous, so that a student in a single laboratory period may have several hundred living paramecia for study. These animals are kept in the laboratory throughout the year, and year after year, so that it is evident that they are active throughout the entire year, although very little is known about their winter activities in nature as contrasted with the artificial conditions in the laboratory.

Appearance.—When a drop of water containing paramecia is placed on a microscopic slide they can be seen with the naked eye as grayish rods moving about rapidly. As soon as they are studied under magnification the body is discovered to have a constant shape which is more like a cigar than any other common object. There is a difference in the form of the two ends of the animal, and that end which usually goes foremost is called the front or anterior end. Paramecium can move either forward or backward, but it swims with the rounded, blunt end pointing in the direction that it is moving except when it becomes necessary to reverse its direction. While it is customary to use the terms anterior for the blunt end and posterior for the pointed end, these two terms do not indicate that there is a clearly defined head or anterior region as in the frog.

The body is broader toward the posterior end, so that the widest part is about two-thirds from the anterior end. In the usual outdoor culture of paramecia there will be found individuals varying in size from 300 micra to as small as 90 micra (a micron is $\frac{1}{1000}$ of a millimeter), which has been shown to be the natural range in size for these single cells of living protoplasm. In such a culture of paramecia it may be possible to distinguish between the larger animals that have the anterior half of the body rather slender and the posterior end markedly pointed; and the smaller forms which are slightly broader in proportion to length and taper less rapidly. When certain additional facts are added to those of size and shape, one can say that two species of paramecia are present.

Structure.—The body of the paramecium is covered with cilia which are slightly longer at the posterior end. On one surface there is a broad groove extending from the anterior end backward obliquely, ending about the middle of the body. As this groove extends posteriorly it deepens. At this place the mouth is located, which opens into a short gullet. For convenience in description the surface upon which this oral groove occurs is referred to as the oral or ventral surface.

The internal structure may be compared to any typical cell with cytoplasm and nucleus. The cytoplasm of the paramecium is easily recognized as consisting of an outer firm layer with very few coarse granules, known as the ectoplasm; and the inner, coarsely granular layer, the endoplasm. The thin layer of ectoplasm contains numerous rod-like structures, the trichocysts (Fig. 70). The ectoplasm is separated from the surrounding water by a thin cell wall (pellicle). Both the ectoplasm and cell wall are penetrated by the gullet and the anal opening which is located in the posterior part of the body. The living cilia are in connection with the living cytoplasm beneath the cell wall.

Between the ectoplasm and endoplasm are located the two con-

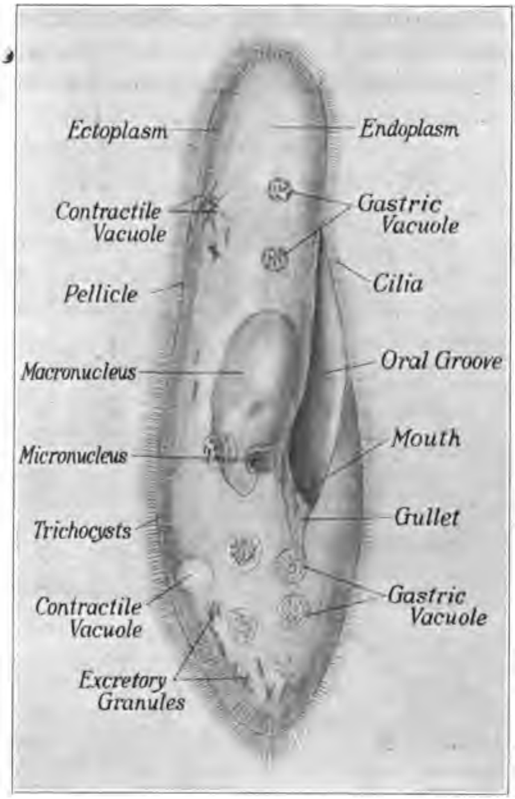


FIG. 70.—Paramecium caudatum drawn from living animal by Geo. T. Hargitt.

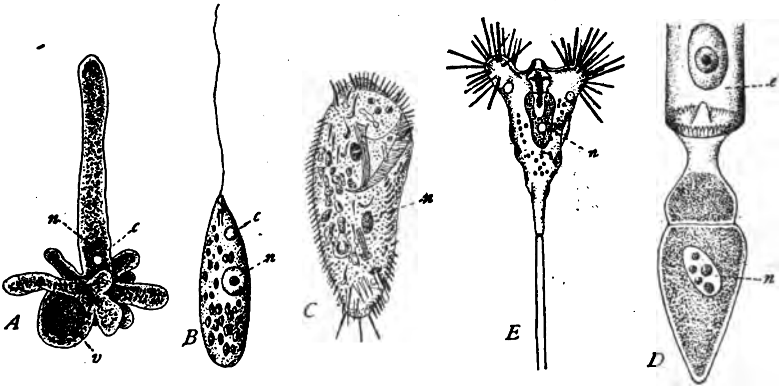


FIG. 71.—Types of protozoa. *A*, *Ameba proteus*, a rhizopod (after Calkins); *B*, *Peranema trichophorum*, a flagellate (after Bütschli); *C*, *Stylonychia mytilis*, a ciliate with specialized cilia (after Bütschli); *E*, *Tokophrya quadripartita*, a suctorian (after Bütschli); *D*, *Pyxinia*, *sp.*, a polycystid gregarine with primite and deutomerite (after Wasielewsky); *c*, contractile vacuole; *e*, epithelial host cell; *n*, nucleus; *v*, food vacuole.

tractile vacuoles, one in the anterior and one in the posterior region. These structures undergo a series of rhythmic changes. There are a number of canals that connect the surrounding region with each

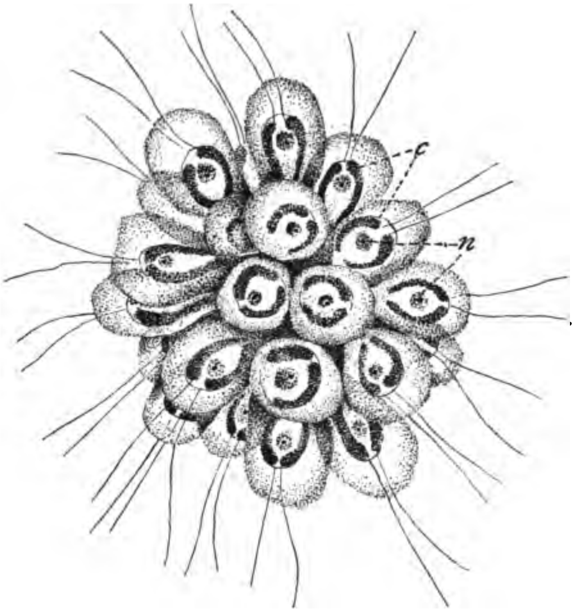


Fig. 72.—*Synura urella*, a colony of phytoflagellates, often a source of disagreeable odors and tastes in drinking-waters. (After Calkins.)

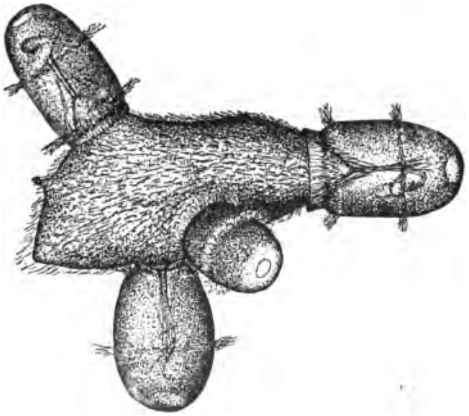


Fig. 73.—A large *paramecium* attacked by four small *didinia*. Under such conditions the *paramecium* is usually torn in pieces and each *didinium* gets a portion. Sometimes, however, one *didinium* gets the entire *paramecium*, forcing the others off during the process of swallowing. (Mast, Biological Bulletin, February, 1909, vol. xvi, No. 3.)

vacuole and as the waste fluid flows through them into the vacuole it gradually becomes distended into a conspicuous vacuole in the part of the body where it is located. As soon as it is filled a contraction takes place in it, and the fluid contents are discharged from the body. The two contractile vacuoles alternate in their action. When one is filling, the other is emptying.

Within the thin peripheral layer of ectoplasm is the coarsely granular endoplasm containing a single large, roundish nucleus and one or two micronuclei which are very minute and usually partly concealed as they lie in a slight hollow in the surface of the macronucleus. The nuclei are located beside the oral groove, near the mouth. There are a varying number of vacuoles scattered in the endoplasm partly filled with food particles surrounded by water. The general term, food vacuoles, may be applied to all such vacuoles. As the animal is studied under the high power of the microscope it is easy to note that the endoplasm is a fluid through which the food vacuoles may move. The nuclei and contractile vacuoles retain their position in the cell but the coarse granules and food vacuoles move about with the streaming movement of the endoplasm. This movement of the endoplasm is independent of the general locomotion of the animal as it swims through the water.

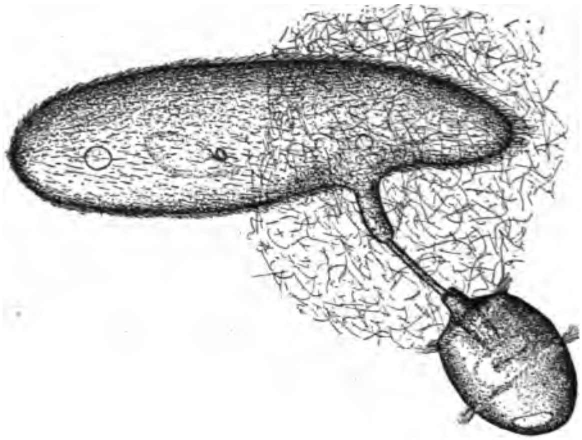


FIG. 74.—A large *paramecium* immediately after having been attacked by a small *didinium*. The discharge of the trichocyst has mechanically forced the *didinium* back, drawing the seizing organ out and producing a marked protuberance on the surface of the *paramecium*. (Mast, Biological Bulletin, February, 1909, vol. xvi, No. 3.)

The single-celled paramecium is thus seen to have more parts than are to be found in the germ cells of a frog or in epithelial cells (Fig. 24). This suggests that these single-celled animals are not all of the same rank, but that some of them have undergone a differentiation and specialization. The paramecium does not represent as simple a form of organization as the ameba and a considerable number of other single-celled animals.

Physiology.—The frog carries on a series of vital activities which are easily compared. The frog utilizes organs and organ systems to do this. The following outline of the vital activities of the paramecium shows that there may be carried on within the protoplasm of a single cell all of the vital processes of the frog.

Locomotion.—No one who has ever observed living paramecia under the low power of the microscope can have any doubt concerning their power to move. While at first their darting movements appear to have no regularity, closer observation reveals that there is a great deal of regularity between what appear at first to be orderless dashings back and forth.

Jennings has given in the following the clearest description found of the general swimming of the paramecium in an unobstructed field: "The parmecium swims by the beating of its cilia. These are usually inclined backward, and their stroke then drives the animal forward. They may at times be directed forward; their stroke then drives the animal backward. The direction of their effective stroke may indeed be varied in many ways. . . . The stroke of the cilia is always somewhat oblique, so that in addition to its forward or backward movement, the paramecium rotates on its long axis. This rotation is over to the left (Fig. 75), both when the animal is swimming forward and when it is swimming backward. The revolution on the long axis is not due to the oblique position of the oral groove, as might be supposed, for if the animal is cut in two, the posterior half, which has no oral groove, continues to revolve.

"The cilia in the oral groove beat more effectively than elsewhere. The result is to turn the anterior end continually away from the oral side, just as happens in a boat that is rowed on one side more strongly than on the other. As a result the animal would swim in circles, turning continually toward the aboral side, but for the fact that it rotates on its long axis. Through the rotation the forward movement and the swerving to one side are combined to produce a spiral course (Fig. 75)."

The movement of the paramecium in an unobstructed field is thus seen to be a regular spiral, which may be said to be as characteristic as is hopping for the frog. But when the paramecium meets an obstacle, another paramecium or food its movements are equally characteristic, and a specific description can be given in each instance. In a more intensive study of the paramecium these various forms of activity are readily distinguished.

Food.—Large quantities of bacteria are present in water in which paramecia are abundant, since these minute plants are their chief food. The activities of the paramecium in feeding consist in placing the body against a mass of bacteria and stopping the action of the cilia on the body, while those on the oral groove produce a strong current of water directed toward the mouth. The bacteria are thus carried to the mouth and swallowed. As the masses of bacteria pass into the endoplasm, a small amount of water is also taken in. The result is the production of a distinct structure, surrounded by endoplasm called the food or gastric vacuole.

The number of food vacuoles depends upon the abundance of bacteria available. As the vacuoles accumulate in the endoplasm, they can be seen to pass posteriorly and then gradually move toward the anterior end, finally, after several hours, being extruded from the body through the anal opening.

Digestion.—The gastric vacuoles in the endoplasm of the paramecium may be compared to the stomach of the frog. Neither the insects which are in the stomach of the frog nor the bacteria in the gastric vacuoles of the paramecium can be built up into living protoplasm until they have been digested. There are no digestive glands or special structures, so far as one can observe, whose main function it is to transform these bacteria, which are composed of proteins, carbohydrates and possibly fats,

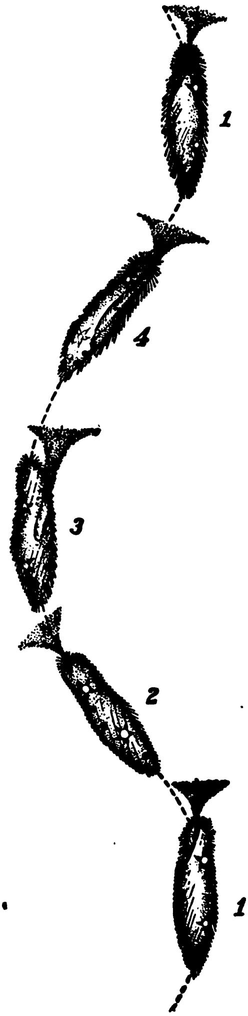


Fig. 75.—Spiral path of a *paramecium*. The figures *1, 2, 3, 4*, etc., show the successive position occupied. The dotted areas with small arrows show the current of water drawn from in front. (From Jennings.)

into diffusible products. It has been demonstrated that there is a mineral acid in the gastric vacuoles which kills the bacteria, after which the bacteria are seen to swell and then pass into solution. This is probably similar to protein digestion in the higher animals. Inasmuch as there are definite digestive ferments or enzymes that transform the food in all of the higher animals, it is assumed that one or more digestive enzymes are produced by the protoplasm of the paramecium because proteins, carbohydrates and fats are absorbed from the gastric vacuoles. The paramecium is thus able to digest and assimilate food in a manner similar to the many-celled animals.

Excretion.—It is believed that the contractile vacuoles collect and discharge waste products to the outside of the body of the paramecium. There are also some specific granules which are regarded as excretory although their exact function is undetermined.

Respiration.—In addition to taking in food and giving off waste, the paramecium must have oxygen. This it is able to take from the water. There is no definite part of the body of the paramecium concerned in taking oxygen that is comparable with the lungs of the frog. As the excretory waste flows into the contractile vacuoles and then is in turn discharged from the body a certain amount of movement is produced in the endoplasm which probably helps in circulation.

Metabolism.—The manner in which the paramecium uses food, the evidences in favor of excretion and the utilization of oxygen warrant the use of the term metabolism in the same sense that it was used in describing similar activities in the frog.

Reproduction.—That this elementary vital process is present in the paramecium is the common observation of students every year. Either cells are seen dividing or swimming about in pairs. The dividing cells are reproducing by a process known as *fission* which is the usual method (Fig. 76). The micronucleus divides first, then the cell divides through the middle of the macronucleus. A new mouth has to form on the posterior half and an extra contractile vacuole in each half. Woodruff has carried on a continuous series of observations upon the species of the paramecium known as aurelia, and this animal has been recorded as dividing for more than 6000 times by the process of fission. Each time that a paramecium divides, there are no parents, but the individual parent has become merged into two offspring. In a species like aurelia it would seem as if one might almost say that it is immortal.

Conjugation.—In both species of paramecia that have been studied there are certain periods when two animals unite temporarily, during which there is a definite exchange of a fraction of the micronuclei. After each paramecium has thus received this small amount of nuclear substance the animals separate. Preceding this exchange of micronuclear material a complicated series of changes takes place in the micronucleus of each. There appears to be a definite fusion between the micronucleus introduced into the paramecium and the portion that remains, with the result that a new micronucleus is formed. After this process, which some writers regard as similar to fertilization in the higher animals, the cell divides by fission, but in this instance the new micronucleus has divided into four nuclei and the macronucleus has broken up into fragments which are gradually absorbed by the protoplasm of the cell. After the cell has thus divided there are two micronuclei in each half, one of which becomes a new macronucleus.

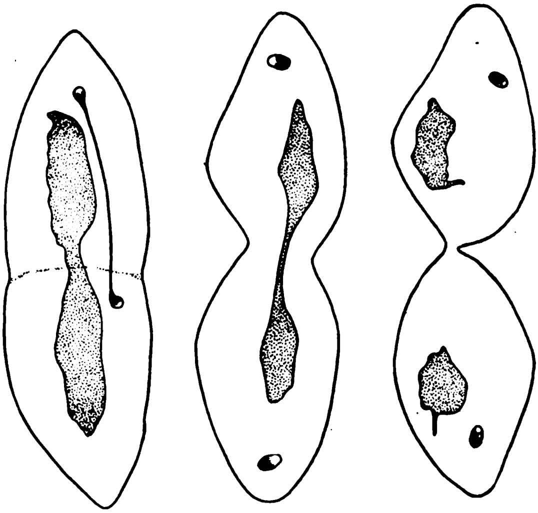


Fig. 76.—*Paramecium caudatum*, showing fission drawn from author's preparations. Notice the irregularity in the outline of the macronucleus which appears to be a normal feature.

Organic Movement.—In order that the paramecium may be able to carry on all of these vital activities, it must have been able to coordinate its movements. In an analysis of these movements it is customary to separate them into the following which are regarded as elementary properties of protoplasm: *Irritability,* which enables the protoplasm to respond to a stimulus; *conductivity,* by means of which the effect of the external stimulus is communicated to all parts of the cell; as these two properties respond the protoplasm contracts, which is the third property, *contractility*. These three are bound up in such a way that the animal is able to move in a definite direction; in other words, to correlate or coördinate its response to a definite stimulus. These are the same reactions that the frog is able to carry on by means of the nervous system and muscles. Jennings, page 261, states several important facts in regard to reaction of single-celled animals, two of which are quoted: "First, we find that in organisms consisting of but a single cell, and having no nervous system, the behavior is regulated by all the different classes of conditions which regulate the behavior of higher animals. In other words, unicellular

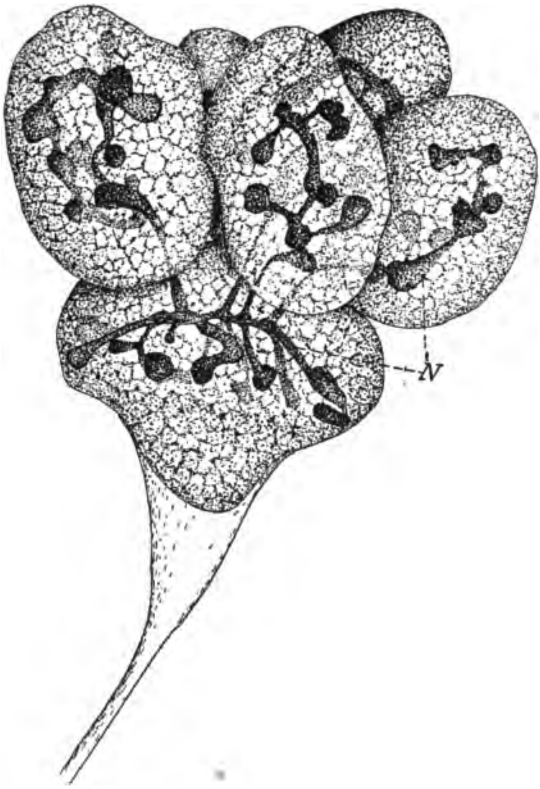


Fig. 77.—*Ephelota bütschliana*, a budding individual with five daughter buds: *N*, macronucleus, which forms a branching organ connected throughout. Reproduction by budding is a form of fission. Notice the branching form of the macronucleus in each bud. (After Calkins.)

organisms react to all classes of stimuli to which higher animals react. Secondly, the reactions produced in unicellular organisms by stimuli are not the direct physical or chemical effects of the agents acting upon them, but are indirect reactions, produced through the release of certain forces already present in the organism. In this respect the reactions are comparable with those of the higher animals."

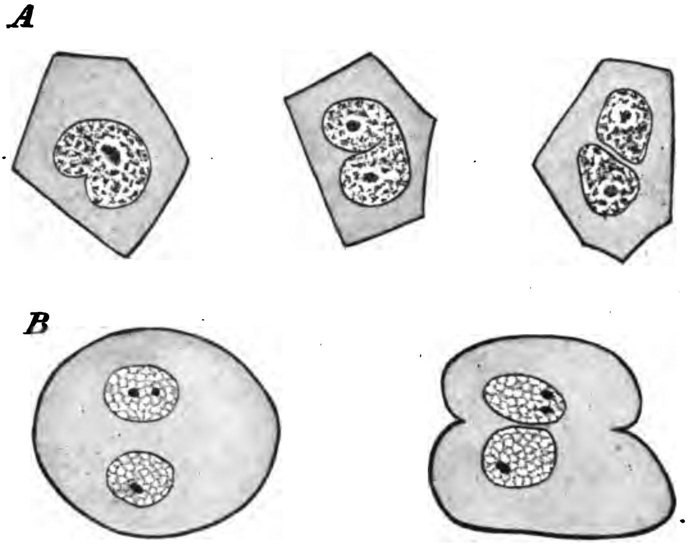


FIG. 78.—Amitotically dividing cells. The division of the cell by fission does not occur as commonly as the indirect method illustrated on page 76. These amitotically dividing cells show how the method of division known as fission takes place in cells in the higher animals. (After Child and Patterson.)

Kinds of Paramecia.—In most cultures of paramecia, there will be found animals which fall into two general classes: (1) "Caudatum Group (Paramecium caudatum). One micronucleus as seen in Fig. 76. Animals larger, slightly more slender, posterior half of body tapering more rapidly and regularly than in the aurelia group. (2) Aurelia Group (Paramecium aurelia). Two micronuclei, unlike the one in caudatum. Animal smaller, slightly broader in proportion to length, and tapering less rapidly from the middle backward than in the caudatum group." (Jennings.)

Protozoa.—The paramecium is a typical protozoan; some protozoa are simpler than the paramecium, others are more complex. There is a wide range of shape and size among the 8000 different species of protozoa. The relation which the paramecium bears to the various classes is shown in the table of classification (p. 299).

Protozoön Animals.—The study of the paramecium serves to show how an animal composed of only a single cell may carry on all of the necessary vital activities of the more complex animal such as the frog. The paramecium is an organism without any of the morphological structures which go to make up the bodies of higher animals. The whole life is lived within the limits of a single cell. In view of the fact that a single protozoön lives but a few hours and then divides, merging its individuality into two or more offspring, one cannot use the term life cycle as it was used in the frog. But the protoplasm of which an individual is composed goes on generation after generation, and to these changes the term life cycle can be given.

Biology of Cells.—The modern study of biology assumes an accurate knowledge of the general features of cell activity and cell structure. This study of the paramecium serves as an introduction to the biology of unicellular organisms. The next two chapters illustrate other phases of this same problem. The three combine to furnish the modern point of view in biology and serve as a background for the remainder of the book.

REFERENCES.

CALKINS: Protozoölogy.

JENNINGS: Behavior of the Lower Organisms.

JENNINGS AND HARGITT: Characteristics of the Diverse Races of Paramecium, Jour. Morphol., vol. xxi.

WOODRUFF: Paramecium Aurelia and Paramecium Caudatum, Jour. Morphol., vol. xxii.

WOODRUFF: Further Studies on the Life Cycle of the Paramecium, Biol. Bull., 1909, vol. xvii.

CHAPTER IX.

PLEUROCOCCUS—A PLANT CONSISTING OF A SINGLE CELL.

Habitat.—Everyone has noticed the greenish layer which occurs so commonly on tree trunks, moist rocks, wooden fences and similar objects. This layer is dull green in color and powdery in texture when dry, but when moistened by rain the color becomes brighter and the layer becomes somewhat slimy to the touch. Under the microscope this green material is found to be composed of thousands of very small cells or groups of cells of the plant pleurococcus. This plant is truly cosmopolitan in distribution, being found in the habitats mentioned in all parts of the world under the most diverse conditions of temperature and moisture. In north temperate regions it is usually found on the north face of vertical objects, *i. e.*, the shaded and moister side.

Morphology.—A single plant of pleurococcus consists of a spherical cell of variable size, ranging from 5 to 15 micra in diameter. Such separate plants are readily found; but more commonly they occur united into groups or colonies of two to a dozen or more cells. In such colonies the individual cells are not spherical but assume various irregular shapes because of the pressure of adjacent cells.

Each plant consists of a protoplast surrounded by a cell wall. The cell wall is thin and transparent and somewhat gelatinous on the outer surface; chemical tests show that it is composed of cellulose. It is non-living, therefore not a part of the protoplast; instead it is formed or secreted by the protoplast. The formation of such non-living cellulose walls is characteristic of plant protoplasts and occurs but rarely in animals.[1]

The protoplast consists of a nucleus and one or sometimes two chloroplasts embedded in grayish or colorless cytoplasm. The nucleus lies near the center of the cell, is spherical in shape and measures from 2 to 4 micra in diameter; it contains one or more nucleoli and shows a netted or reticulate structure which includes the chromatin. The chloroplast is bowl- or trough-shaped with the convex surface outward; it lies near the surface of the protoplast but is wholly surrounded by cytoplasm. In an isolated plant of spherical shape it may almost entirely surround the nucleus; but in cells which form part of a colony it is smaller and assumes a position in the curved

---

[1] In this chapter certain terms of current botanical usage are applied to both plants and animals; this seems desirable in order to facilitate comparison of the structures and processes of the two groups of organisms.

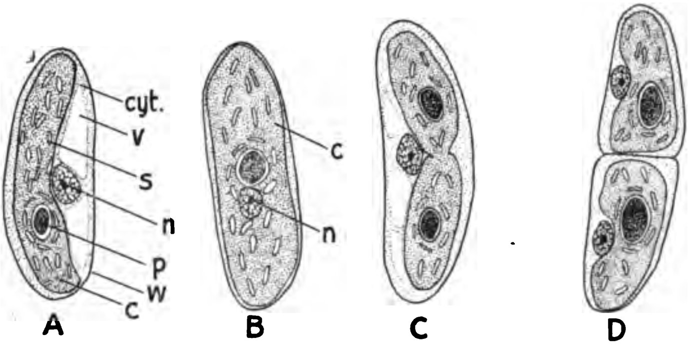


FIG. 79.—*Mesotænium*, a unicellular green plant. *w*, cell wall; *cyt.*, cytoplasm; *v*, vacuole; *n*, nucleus; *c*, chloroplast; *p*, pyrenoid; *s*, starch grain. The chloroplast is a thick, curved plate; side and top views of it are shown in *A* and *B*. *C*, *D*, stages in reproduction by cell division. × 1070.

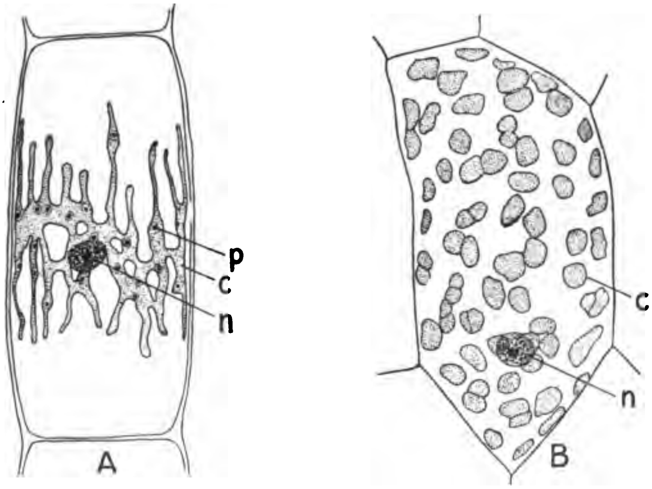


FIG. 80.—Surface views of plant cells, showing different forms of chloroplast. *c*, chloroplast; *p*, pyrenoid; *n*, nucleus. *A*, cell of *Draparnaldia*, with single elaborate chloroplast; *B*, cell of fern prothallium with many simple chloroplasts. × 680.

part of the cell, *i. e.*, in the part most immediately exposed to light. The chloroplast of a living plant of pleurococcus is bright green in color, due to the presence within it of the pigment chlorophyll. If the cells are placed in alcohol the chlorophyll is dissolved out; the chloroplast is seen to be unchanged except in color, which is now grayish, while the chlorophyll, if present in sufficient quantity, colors the alcohol a characteristic green. It is important to note this distinction between the chloroplast, which is a living organ of the protoplast, and the chlorophyll, which is a green pigment contained in the chloroplast.

Photosynthesis.—As already explained (page 35) the food of animals consists for the most part of organic substances of three groups: carbohydrates, proteins and fats. The same is true of plants, and we may therefore say that the food of all organisms is essentially the same and consists of organic substances of the three groups named. But if we examine the source of the food of an animal, *e. g.*, the frog, we find that all of it is derived from other organisms—insects, worms, plants, etc. Hence such organisms as the frog are dependent, or, as we say for plants, heterotrophic in nutrition, *i. e.*, they are dependent upon other organisms for food. If, on the other hand, we study the nutrition of a green plant such as the pleurococcus it becomes plain that its food is not brought in from outside the organism but is manufactured *in situ* from inorganic materials. Such organisms are independent or autotrophic in nutrition, *i. e.*, they are capable of manufacturing their own food and so are independent of other organisms.

In general, green plants are autotrophic; conversely, plants lacking chlorophyll, such as mushrooms, etc., and all animals, are heterotrophic. In short, with the exception of a few bacteria, all autotrophic organisms possess chlorophyll and owe their power of food manufacture to it; and all other organisms secure their food directly or indirectly from the autotrophic ones.

Chlorophyll is formed only within chloroplasts except in the simplest green plants (Schizophyceæ), where chloroplasts are lacking and the chlorophyll is distributed throughout the protoplast. It is readily soluble in alcohol, ether, benzol and other reagents; the solution shows the characteristic green color by transmitted light, but under strong reflected light appears a deep blood red. Chemically, chlorophyll is a complex compound of carbon, hydrogen, oxygen, nitrogen and magnesium; its probable empirical formula is given by one investigator as $C_{54}H_{72}O_6N_4Mg$. While not a constituent of chlorophyll, iron is always present in the chloroplast and seems to be essential to chlorophyll formation. Either in solution or in the living plant chlorophyll absorbs part of the light which falls upon it. As shown by the spectroscope, this absorbed light consists of a series of rays of various wave-lengths; but for the most part the absorption is of the red-orange and blue-violet rays while the yellow-green rays are transmitted unhindered. The energy of the light thus absorbed in the chloroplasts is available for the work of the plant and is used to bring about the manufacture of food. Obviously, therefore, the process can go on only in the presence of the light necessary to afford the energy, *i. e.*, in nature, in the daytime.

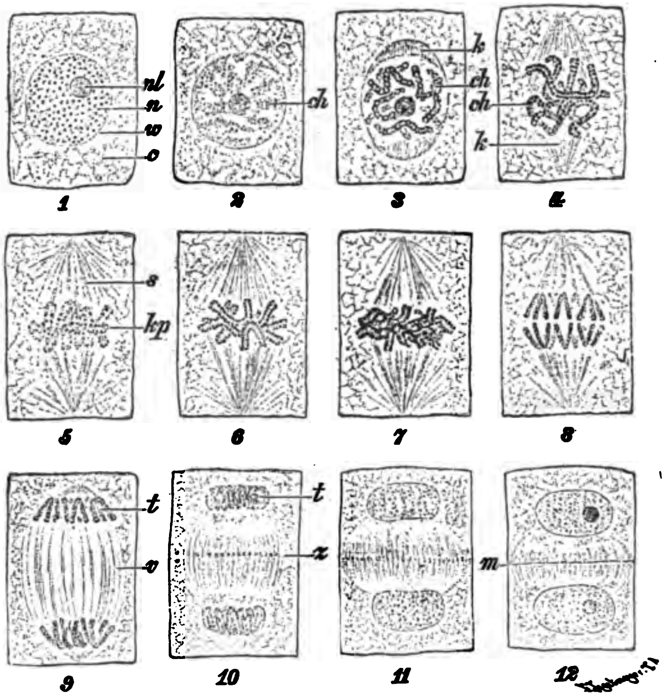


FIG. 81.—Scheme of indirect cell division in plants. *n*, nucleus; *nl*, nucleolus; *w*, nuclear membrane; *c*, cytoplasm; *ch*, chromosomes; *s*, spindle fibers; *v*, connecting fibers; *z*, cell plate; *m*, new cell wall. *1*, nucleus in resting condition with chromatin in granular or reticulate condition; *2*, *3*, *4*, chromosomes are organized from the chromatin, and split longitudinally; nuclear membrane disappears; *5*, *6*, *7*, chromosomes arrange themselves in a plate across the center of the cell; spindle fibers form; *8*, *9*, halves of the chromosomes separate and move to the poles of the cell; *10*, *11*, *12*, daughter chromosomes organize new nuclei; cell plate appears on connecting fibers and forms new cell wall. (Strasburger, Noll, Schenck and Karsten.)

The materials from which carbohydrate food is manufactured by green plants are two in number, carbon dioxide and water. Carbon dioxide is present in the atmosphere in the small but constant concentration of about 3 parts per 10,000 parts of air, and is therefore readily available to such plants as the pleurococcus. Water is absorbed directly from the substratum through the cell wall into the protoplast. The carbon dioxide taken in is dissolved in the water in which it is readily soluble. While the exact steps in the process of formation of carbohydrate foods from these substances are not yet clear, the essential facts are well established. The carbon dioxide and water are partially or completely reduced to their elements, which immediately recombine to form a monosaccharide sugar (probably dextrose) with the freeing of oxygen. These two processes are represented by the reaction $6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$. The oxygen is given off into the atmosphere through the cell wall. The sugar is the primary food of the plant, being the principal material used in the synthesis of other foods and in the processes of metabolism. When it is produced in excess of the immediate requirements a further reaction takes place by which some of the water is eliminated and the sugar is "condensed" into starch; this reaction is $n(C_6H_{12}O_6) = (C_6H_{10}O_5)n + n(H_2O)$.

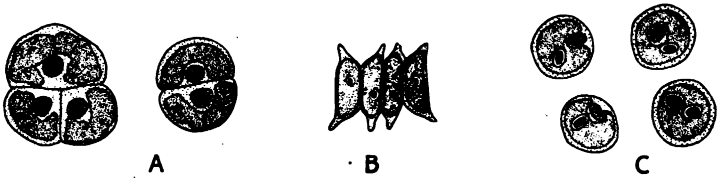


Fig. 82.—Colonies of various unicellular green plants. *A*, *pleurococcus;* *B*, *scenedesmus;* *C*, *tetraspora.* × 800.

This starch is deposited in the chloroplast as granules or "starch grains" and forms a reserve food supply for the cell; in green plants kept in darkness the starch grains soon disappear and reappear only after the plant has again been in the light for a considerable period of time. In some plants, *e. g.*, vaucheria, the excess food is stored in the form of a fat or oil, but it is probable that here also the first food formed is a sugar.

This process by which carbohydrates are manufactured in green plants is called photosynthesis; its essential features are summarized as follows: The materials used are carbon dioxide and water; the energy is obtained from sunlight absorbed by chlorophyll; the chloroplast by the use of this energy brings about a chemical synthesis of the materials, resulting in the freeing of oxygen and the production of a sugar, some of which is usually transformed into starch and stored in that form.

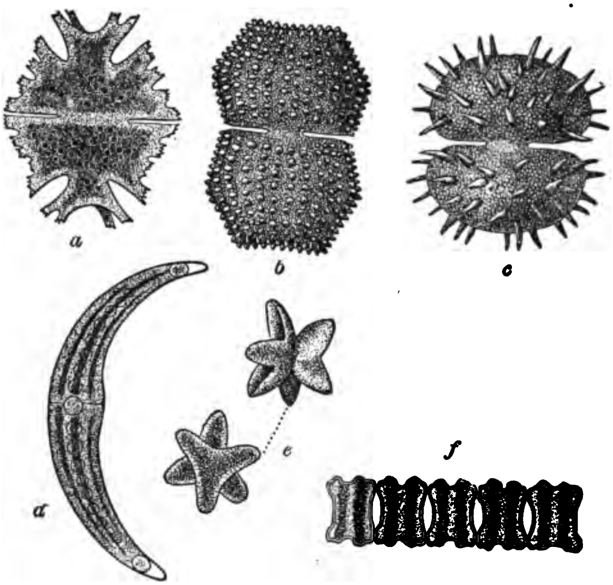


Fig. 83.—Various desmids. *a*, *Micrasterias;* *b*, *Cosmarium;* *c*, *Xanthidium;* *d*, *Closterium;* *e*, *Staurastrum;* *f*, *Aptogonum.* × 200. (After Kerner, from Barnes' "Plant Life.")

Other Materials and Syntheses.—In the life processes of green plants certain mineral substances are necessary in addition to the carbohydrates produced by photosynthesis. As mentioned above, magnesium is a constituent of chlorophyll and iron is always present in the chloroplast; these elements are therefore essential to the metabolism of green plants. In addition to these, nitrogen, potassium, phosphorus, calcium and sulphur are required by most plants. In the case of simple forms like the pleurococcus the very minute quantities of these that are necessary are contained in the form of soluble compounds in the water taken in. From the sugar produced by photosynthesis, together with nitrogen and sulphur taken in in this way, various proteins are produced by the living protoplast. The details of protein synthesis in plants are for the most part unknown, but the process is probably enzymatic in character. By similar processes fats are also formed from carbohydrates. This occurs in the pleurococcus especially at periods when the plants have become very dry and are in an inactive or resting condition; at such times little or no starch is formed, while fats are present in quantity.

Metabolism.—As already defined (page 47), metabolism includes all the processes which have to do with the use of food by the organism. These processes in simple plants, such as the pleurococcus, differ in no essential features from the corresponding processes in the paramecium and other simple animals. The foods produced by the processes just described are assimilated by the protoplast, resulting in the formation of new protoplasm and consequent growth of the cell. Similarly, the process of respiration takes place continually in the pleurococcus as in all other organisms, resulting in the formation of carbon dioxide and water and the releasing of the energy necessary for all the life processes of the protoplast, except photosynthesis (page 99).

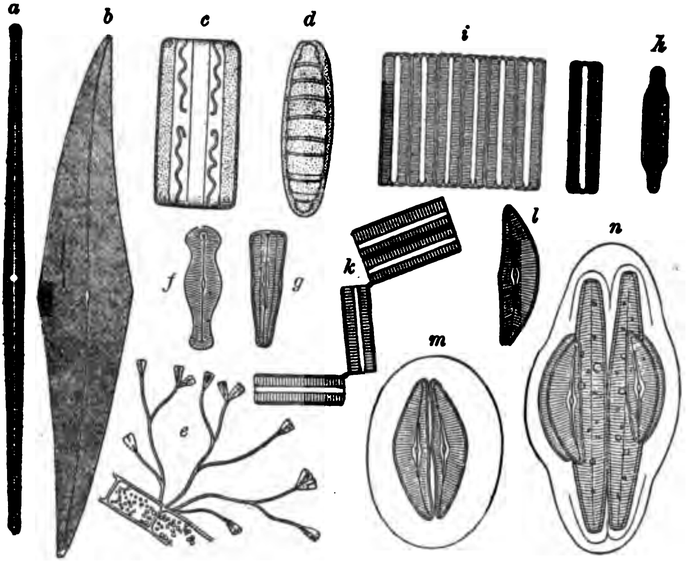


Fig. 84.—Various diatoms. *a*, *Synedra; b*, *Pleurosigma; c*, *d*, *Grammatophora*, side and top views; *e*, colony of *Gomphonema*, with branched stalks; *f*, *g*, single cells of same, top and side views, more highly magnified; *k*, colony of *Diatoma*, the cells connected into a zig-zag band *h*, *i*, colony and individuals (top and side views) of *Fragilaria; l*, *m*, *n*, *Cocconema*. (After Kerner, from Barnes' "Plant Life.")

Reproduction.—As a result of the assimilation of food, growth of all parts of the cell results. The cell wall is elastic and is stretched by the increased volume of the protoplast; its normal thickness is maintained by the deposition upon its inner surface of new layers of cellulose by the protoplast. The chloroplast also enlarges and ultimately divides into two. The nucleus enlarges for a time, then divides mitotically (page 74). A cell wall is formed between the two daughter nuclei, dividing the original cell into two similar cells each containing cytoplasm, a nucleus and a chloroplast. The newly formed cells may separate at once, or they may adhere for a time, forming groups or colonies of cells. This simple division of the original plant to form two plants is the only form of reproduction known to occur in the pleurococcus.

Other Unicellular Green Plants.—Microscopic examination of water from ponds, streams or laboratory aquaria will usually show some forms of unicellular green plants. Especially common in aquarium jars is Scenedesmus, with spindle-shaped cells grouped in colonies of four. Pond waters usually contain numerous desmids (Closterium, Cosmarium, etc.), which are characterized by curiously shaped bilaterally symmetrical cells with very complex chloroplasts. Diatoms, with cell walls of silica instead of cellulose and containing a brown pigment in addition to chlorophyll, are abundant in all waters and moist places.

CHAPTER X.

BIOLOGY OF BACTERIA AND YEAST—THE SIMPLEST LIVING ORGANISMS.

Organized Ferments.—This chapter is limited to a general survey of the more important of the so-called organized ferments. This expression was applied at first to such forms of cell life as have the ferment associated with the life of the cell, and in one sense the term organized ferments may be retained, since in nature these intracellular[1] enzymes are found acting through the living protoplasm that produces them. They are not poured out as is the saliva or the pepsin, which may be described as extracellular enzymes. It was believed for many years that these ferments could not be separated from the protoplasm which produced them and that their ferment action ceased with the death of the protoplasm. Buchner demonstrated that yeast could be ground with infusorial earth and a juice extracted which had the power to cause alcoholic fermentation. The yeast plant may be killed by alcohol, ether, or acetone and still retain its power to cause fermentation. In a similar manner the bacteria which cause lactic acid in milk can be killed, so that they do not grow or divide, and yet they can form lactic acid. These experiments are difficult to perform, but are valuable as showing that the enzymes are to be classed as similar to those found in the higher animals and plants.

Yeast.—The word yeast is a general name for a half-dozen or more distinct species of plants found growing wild and cultivated. Because yeasts feed upon sugar, the term saccharomycetes is given them. These plants are necessary in bread-making and in the manufacture of liquors. If yeast is to grow and thrive the temperature may range from 9° to 60° C. When dried it can endure a higher temperature but it requires a definite environment if it is to live.

Morphology of Yeast.—If a small amount of compressed yeast is mixed with water and then examined with the microscope, a large number of oval and egg-shaped bodies are seen. The majority are either unicellular or have small buds attached. Sometimes a short chain of buds is noted. There is a definite cell wall composed of "yeast cellulose." The living protoplasm is granular and usually contains a number of vacuoles filled with sap. The beginning student frequently mistakes the sap vacuoles for the nucleus. Many minute glistening dots can be made out which are probably fat. No chlorophyll or starch is found in the protoplasm. The nucleus is a coarsely granular body and can be differentiated by the use of proper stains.

---

[1] Vernon: Intracellular Enzymes, 1908.

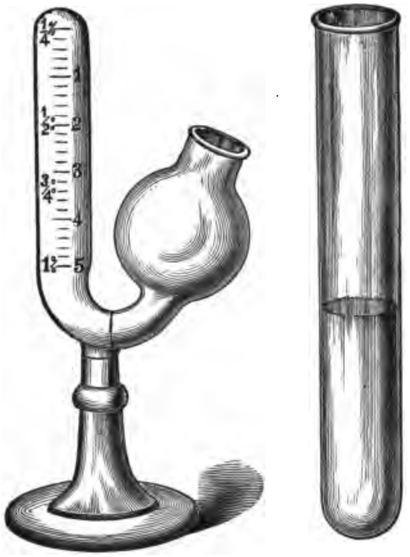


FIG. 85.—Einhorn's saccharimeter.

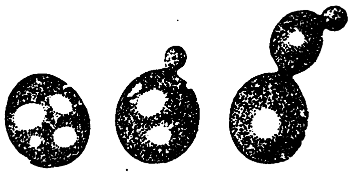


FIG. 86.—*Saccharomyces*, yeast cells. (From Verworn, after Reinke.)

Reproduction of Yeast.—The usual process of reproduction is easily seen in any study of yeast in water. The method is similar to fission in protozoa, except that there is a large parent mass and a small offspring. The nucleus divides by amitosis and the bud remains attached for some time. Occasionally yeast exhibits the formation of spores by a process which results in dividing the protoplasm of the cell into two, three, or four distinct masses. When the old cell wall breaks down under proper environmental conditions each spore is capable of starting a new series of yeast plants.

Food of Yeast.—Pasteur devised a solution which contains no organic nitrogenous matter, the nitrogen is in a more complex compound than the nitrates, which are utilized by green plants (see p. 99).

Water, H_2O	83.76	per cent.
Cane-sugar, $C_{12}H_{22}O_{11}$	15.00	"
Ammonium tartrate, $(NH_4)_2C_4H_4O_6$	1.00	"
Potassium phosphate, K_3PO_4	0.20	"
Calcium phosphate, $Ca_3(PO_4)_2$	0.02	"
Magnesium sulphate, $MgSO_4$	0.02	"
	100.00	"

The yeast is able to grow in this fluid and to make more protoplasm; it must therefore have been able to utilize inorganic material as the whole source of its food energy. This is a physiological property that is probably lacking in the unicellular animals, although some recent researches assign a rather higher synthetic power to animals. The green plant cells are able to utilize simpler nitrogen compounds than is the yeast, so that the yeast occupies an intermediate position between animal and green plant cells in its ability to manufacture its own food out of the raw elements. It can use nitrogen in the higher forms of proteins, and in this sense approaches more closely to the animal cell. Free oxygen is as necessary to yeast as to other forms of living matter. The anaërobic bacteria such as the intestinal bacilli and many others are the only exceptions to this general statement.

Metabolism.—The yeast plant is able to build up its own food from the mineral substances furnished in Pasteur's solution and to utilize them in the making of more yeast protoplasm. The series of changes through which foods must pass in becoming living protoplasm we must believe are similar in all forms of life. There is then in the yeast plant digestion of foods by intracellular enzymes. It is probable that there is a separate form of enzyme for the protein digestion and another for the carbohydrate. The digestion of the foods must be followed by a series of up-building stages which finally result in the food becoming protoplasm. The yeast does work in growing new cells and causing fermentation, as in bread, where the temperature is raised by the fermentation process. This requires energy and is an outgo from the cell. To this may be added carbon dioxide and nitrogenous wastes, although these wastes are masked in part by the presence of other substances in the culture solution.

BACTERIA.

Relationships.—There has been much discussion in the past as to the general relation of the bacteria, whether they should be grouped with the plants or the animals. They are related more closely to a group of algæ known as the blue-green algæ than to any other definite group of plants or animals. Their method of locomotion and in some instances the manner of spore formation reveals well-recognized protozoan traits. In the main they are best regarded as plants because of their power usually to live without already prepared protein food and because of their method of reproduction. In their general physiology they are more like fungus plants and so are classed under the fungus term (mycetes) as *schizomycetes.*

Morphology.—Bacteria appear in three general shapes—the straight rod (bacillus), the bent rod (spirillum), and the sphere (coccus or micrococcus). "There are spherical forms of wide difference in sphericity, rod forms with great variation in length and diameter, and spiral forms having from a fraction of one spiral to many spirals. Furthermore, spherical forms may become piled upon one another so that colonies result, and rods may be jointed in such a way as to construct filaments. Within these groups many species of bacteria are known. One high authority, Migula, considers that there are 1272 distinct species of bacteria, most of which belong to the bacillus type." (Bergen and Caldwell.) Some single species such as Bacteria pestis and Bacteria diphtheriæ exhibit considerable variation when studied under different conditions of growth, appearing first in one shape then in another. Such changes are, however, never permanent, but they illustrate the fact that the morphology of bacteria is not a safe method upon which to determine species.

Size.—"The bacteria were formerly spoken of as the smallest of living things, but since the recognition of ultramicroscopic organisms it is necessary to be more specific in characterizing their dimensions. The unit of measurement in microscopy is the micron (μ) or micromillimeter. This is 0.001 of a millimeter or approximately $\frac{1}{25000}$ of an inch. Applying this unit to bacteria we find that the micrococci and the short diameter of the bacilli and spirilla average about 1 μ. The micrococci vary in diameter from a small fraction of a micron to three or four microns. The bacilli are sometimes very small, as the influenza bacterium, with a width of 0.2 μ and a length of 0.5 μ, and

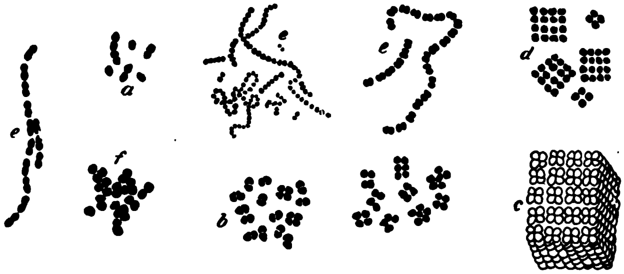


FIG. 87.—Varieties of spherical forms: *a*, tendency to lancet-shape; *b*, tendency to coffee-bean shape; *c*, in packets; *d*, in tetrads; *e*, in chains; *f*, in irregular masses. × 1000 diameters. (After Flügge.)

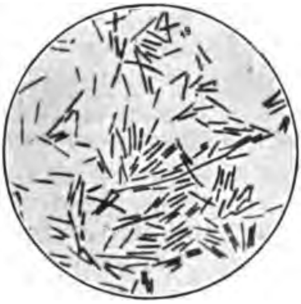


FIG. 88.—Long slender bacilli. × 1000 diameters. (After Park.)

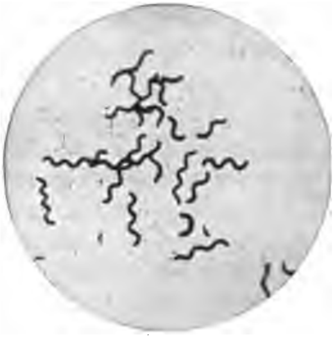


FIG. 89.—Very large spirilla. (After Park.)

FIG. 90

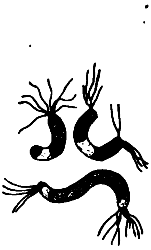


FIG. 91

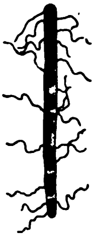
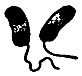


FIG. 92

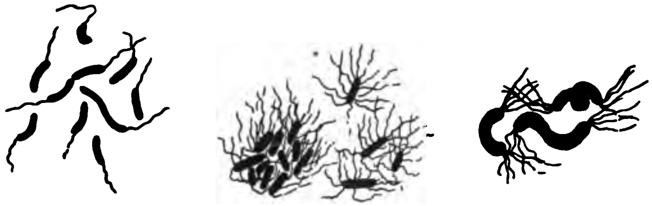


FIGS. 90, 91 and 92.—Fig. 90, Spirillum undula; Fig. 91, Bacillus solmsii; Fig. 92, Vibrio choleræ. The flagella are well shown. (After A. Fischer.)

sometimes very large, as for example the Bact. anthrax, with a width of 0.2 μ and a length of 5.2 μ. The spirilla average about 1 μ in diameter, but may be as long as 30 or 40 μ." (Frost.)

Structure.—Bacteria are extremely simple plants and are regarded by many as the simplest known living things. The cell wall is usually surrounded by a slimy or gelatinous capsule and is not like the cell wall of the higher plants, which is composed of cellulose. Their diminutive size prevents one from learning very much about the cytoplasm. There is no distinct nucleus. The essential part of this organ is believed to be represented by certain granules. From the cell wall in some species a number of cilia or flagella project which are used in locomotion.

Fig. 93 Fig. 94 Fig. 95



Figs. 93, 94 and 95.—Fig. 93, spiral forms with a flagellum at only one end; Fig. 94, bacillus of typhoid fever with flagella given off from all sides; Fig. 95, large spirals from stagnant water with wisps of flagella at their ends (*Spirillum undula*). (After Abbott.)

Motility.—The organs of locomotion are used by the bacteria in moving from place to place. "Some dart with great rapidity, others move slowly; some move in straight lines, others wobble, but any particular character is quite constant, and many of the bacteria may be recognized by their characteristic movements. Their rate of movement varies greatly with the species. As they are viewed under the microscope their motion seems very rapid. The typhoid bacillus has been estimated to travel 2000 times its own length in an hour, while the cholera spirillum may go 45 times as fast. It is probable that their rate is relatively little greater than that of a trotting horse."

Reproduction.—"This is accomplished by means of binary fission. When a bacterium has reached maturity, fission begins. This change in the cell is not customarily regarded as preceded by any series of changes comparable to karyokinesis (mitosis) in the higher cells, since no nucleus in the ordinary sense has been demonstrated in the bacterial cell. Division begins by an invagination of the protoplasm in the middle of the cell, which proceeds until the cell protoplasm is completely separated. The cell wall then grows in and finally splits, forming the two ends of the new cells. These new cell walls are formed at right angles with the long axis of the cell in the case of the bacilli and spirilla, except in rare instances. In the case of micrococci the throwing of the cell wall across one diameter is quite as economical as any other and may therefore proceed in any direction. Migula makes a considerable point of the fact that bacilli and spirilla elongate before division and micrococci divide before they elongate, and this is the criterion which he would use to separate these two-form types. A generation among the bacteria is from one division of the cell to another. This is sometimes very short, in fact, only twenty to thirty minutes. Many of the bacteria after a half-hour's time have grown from newly formed cells to maturity and are ready to divide again. This makes it possible for bacteria to multiply with great rapidity, and if we know the length of the generation in a particular bacterium, it is easy enough to estimate the rate of multiplication, at least theoretically. It is of course quite impossible for the bacteria to maintain their theoretical rate of growth for any length of time because of the formation of by-products, but they grow with enormous rapidity, as is shown in cultures and in the changes which they bring about in nature, such as the production of fermentation and the generation of toxins." (Frost.)

Under certain conditions a considerable number of bacteria form spores (endospores). The protoplasm is broken up into a number of bodies within the cell, which are then called endospores. Their chief value seems to be to enable the bacteria to undergo unusual and unfavorable conditions. In this condition, bacteria possess remarkable powers of resistance.

Zoöglea.—The mother of vinegar illustrates a special habit of certain bacteria. The cells secrete a mucilaginous substance that causes them to cohere in great numbers. In some instances this condition represents a stage in the life history, while in the vinegar it is induced by the formation of a certain amount of acetic acid.

Metabolism.—Fischer divided bacteria into three groups, according to the nature of their metabolism. (1) Bacteria which are like the green plants in requiring neither organic carbon nor organic nitrogen. These are the so-called prototrophic bacteria, which possess the remarkable property of being able to build up both carbohydrates and protein out of carbon dioxide and inorganic salts. (See page 99.) (2) Bacteria which need organic carbon and nitrogenous compounds. These are called the metatrophic bacteria. (3) The paratrophic bacteria which live as true parasites and can exist only within the living tissue. This group cannot manufacture their own food and are like animals in this respect. The metabolism of bacteria may then show all of the phases already described for green plant cells and for animal cells as well as certain additional phases. The food is absorbed directly through the cell wall and is as varied as is their habitat. There seems to be no form of organic substance living or dead that may not serve as a source of food supply for bacteria, so that the enumeration of their foods becomes practically impossible. A special phase of the metabolism of bacteria is illustrated in their relation to nitrogen compounds. Nitrogen in an uncombined state cannot be used as food energy by most plants. It is obvious that the amount of ammonia, nitrites, and nitrates would soon become exhausted unless there were some way of supplying more of the nitrogen compounds. Many of the soil bacteria are prototrophic in habit and carry on the important work of combining the free nitrogen into a form that can be used by other organisms. The several nitrogen combinations are effected through the agency of several kinds of bacteria. There are also bacteria which live in the roots of certain plants, like clover, beans, and peas, which are able to utilize the nitrogen of the air. All of the higher forms of plants and all of the animals are dependent upon microscopic bacteria for their nitrogen. It would be very strange if the character of metabolism which is so fundamental in living things should be essentially different in bacteria; it probably is not, and so the usual steps in assimilation and dissimilation may be assumed to take place in bacteria. During this process enzymes are utilized and toxins produced.

Enzymes and Toxins.—"Among the most interesting and least understood products of microbial action are the enzymes and the toxins. These two groups are related in many respects. Toxins and enzymes are formed by the cells in such small quantities that they would never have been discovered by ordinary chemical means were it not for the unusual effects which they produce, the enzyme acting upon food substance and the toxins acting physiologically upon organisms. Toxins and enzymes are chemically unknown." (Hahn.)

Zoötoxia of the rattlesnake is the best-known animal toxin, while phytotoxins in plants are more common. Toxins and enzymes are both very sensitive to heat, light, and certain chemicals. Both of these bodies must be defined in terms of what they do.

Fermentation.—The organized ferments all employ the same general method to effect changes in the substances upon which they act. The change due to these minute plants, bacteria and yeast is very great and yet it can nearly all be reduced to a process of fermentation. In the ordinary processes of fermentation the chemical compound is simplified. This is easily understood from the following:

Sugar.		Yeast or bacteria enzyme.		Alcohol.		Carbon dioxide.
$C_6H_{12}O_6$	+	? ? ?	=	$2C_2H_6O$	+	$2CO_2$

Alcohol.		Oxygen.		Acetic bacteria enzyme.		Acetic acid.		Water.
C_2H_6O	+	O_2	+	? ? ?	=	$C_2H_4O_2$	+	H_2O

In this transformation through the action of the yeast enzyme and acetic bacteria enzyme the sugar molecule has become much simpler and the ultimate result is a substance entirely different from sugar, namely, vinegar. The changes are chemical in their nature. It is difficult to make any classification of ferments that is not open to criticism. There are the intracellular and extracellular enzymes that act upon the carbohydrates, proteins and fats; these with the oxidizing and reducing enzymes may serve, however, to give a working classification.

CHAPTER XI.

WHAT IS LIFE?

In the study of the living frog there was no question but that it was alive because it was able to move. It was also possible to observe a number of other life processes in the frog such as breathing, eating, reproduction, etc. The paramecium studied next was obviously alive for the same reasons. It was more difficult to detect these same vital activities in the simple green plant cell but still they could be made out. In the yeast and bacteria it was found that some of the vital processes were neither clearly like the animal nor like green plants but rather of a more primitive nature. This primitiveness of some of the vital processes in bacteria has led recent writers to declare that bacteria represent the most primitive forms of life.

New frogs were seen to develop from frog eggs, the paramecium divided and new paramecia resulted. In a similar manner new plants come into existence. The observations of the past forty years have conclusively shown that no new organism has been produced except through the influence of a previously existing like organism. This is an established generalization in biology and is known by the term *biogenesis—the theory that life is generated from living beings only.*

Spontaneous Generation or Abiogenesis.—The view that life could come into being without the influences of preëxisting life or from inorganic matter was held for some twenty centuries beginning with Aristotle, 325 B.C. to Tyndall, 1876. For the ancients there was no difficulty in explaining the occurrence of new animals as complex as insects or even fish. The grotesque extremes to which this easy way of accounting for living things was carried is illustrated by both Virgil and Ovid, who described bees swarming forth from the putrid bowels of the recently killed steer. Frogs, toads, rats, and fish were easily conjured from the mud of ponds and streams by the vivifying action of the heat of the sun. Among children and ignorant persons there still lingers a belief that a horse hair placed in water may become a living worm, as well as other similar crude notions about the origin of living things. This idea that life could not come from non-living matter was first successfully questioned by Redi, 1680, who proved that maggots would not grow in meat, if the flies were prevented from laying their eggs on the meat. Huxley says of Redi, "The extreme simplicity of his experiments, and the clearness of his arguments, gained for his views and for their consequences almost universal acceptance."

Seven years after the experiments of Redi, microscopic animals and plants were discovered and the theory of spontaneous generation took on a new lease of life, as it was used now as an explanation for these minute forms of life. The Italian, Spallanzani, 1777, the Frenchman, Pasteur, 1864, and the Englishman, Tyndall, 1876, are the three great men who successfully devised experiments that conclusively demonstrated that microörganisms did not arise spontaneously. These experiments which established the theory of biogenesis for all of the forms of life which are known to science should be read in this connection. (See references at close of chapter.)

There is no longer any controversy among scientific men as to how present-day animals and plants came into existence, for they can be proved to have been derived biogenetically. But there still remains the question of the first origin of life or whether it arose more than once as the cooling earth took shape. There have been a number of attempts to answer these last two questions but up to the present there is no way of knowing what may have happened in the prehistoric ages of geologic history.

There is still much to be learned about living protoplasm, and while it is possible that man may not completely solve all of the mysteries locked up within the body of a paramecium, it is desirable to keep on investigating. At present protoplasm is being studied from the chemical, physical and biological points of view, each of which are briefly summarized in the following pages.

Chemical Composition of Living Matter.—When life is studied from the chemical point of view the results tell us what chemical bodies are present. No one has been able to write the chemical formula for living matter, and after all of these years but little is known of the chemistry of living matter. One of the reasons for this lack of chemical knowledge is that as soon as a chemical analysis is applied to living protoplasm, it becomes dead and science has yet to prove that the chemistry of dead protoplasm is the same as of living protoplasm. Whether future research reveals that dead and living protoplasm are essentially the same or not, we already know what chemical elements occur in protoplasm.

There are some eighty-two different chemical elements known to science and not more than twenty-nine of these ever occur in living protoplasm. Twelve of these are but rarely found while four are of frequent occurrence. The remaining thirteen are invariably found and believed to be essential to life. These are hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, iron, sodium, chlorine, and silicon. These elements are the most numerous in the rocks, water and atmosphere. But the amount of these elements, even those that are essential to life, found in an organism bears no relation to their abundance in nature.

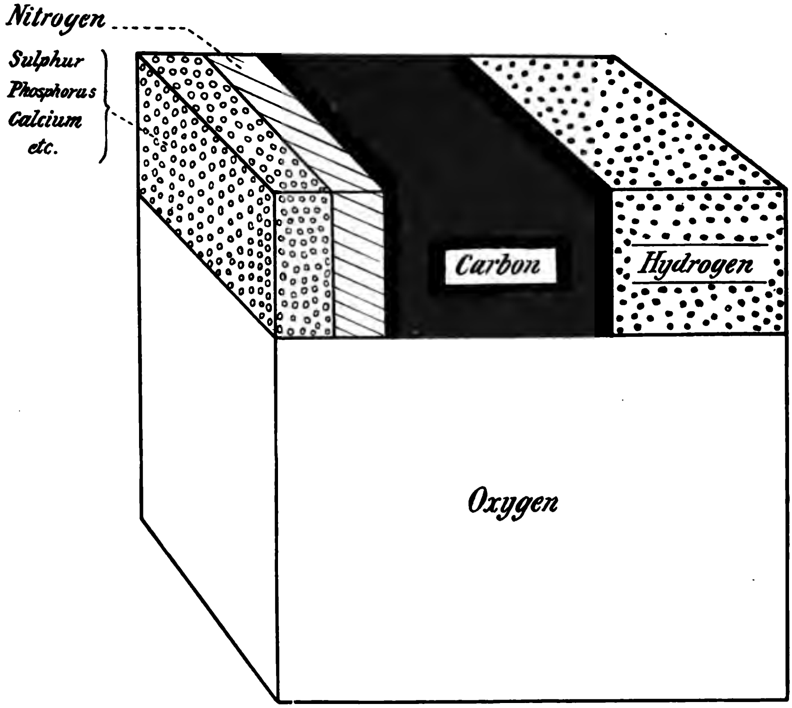


Fig. 96.—Diagram to show the proportionate amounts of the chemical elements in living things.

The following summarized account, from Starling, of the most important elements shows their relations in nature: "Carbon forms the greater part by weight of the solid constituents of living protoplasm. In the inorganic world practically all of the carbon occurs in a completely oxidized form, namely, carbon dioxide. A small amount, 4 parts in 10,000, is present in the atmosphere, while vast quantities are buried in the crust of the earth as carbonates. Practically all of the carbon in organic tissues is derived from the minute proportions of carbon dioxide present in the atmosphere. This is combined through the work of the chlorophyll into carbon compounds that can furnish energy to living matter. Hydrogen exists almost exclusively in the form of water. In this form it is taken up by plants and animals, with the exception of a small amount absorbed in the form of ammonia. Oxygen is the only element which, in all the higher organisms, at any rate, is taken up in the free state. It forms one-fifth of the atmosphere and, as the oxides of the various metals a considerable fraction of the earth's crust; it takes a position apart from the other foodstuffs in that its presence is the essential condition for the utilization of their potential energy. Nitrogen constitutes four-fifths of the surrounding atmosphere, and can be utilized by most plants only in the form of ammonia, nitrites, or nitrates. To animals these compounds are useless, and the only source of nitrogen for this class is protein. Sulphur is found in all soils in the form of sulphates, in which form it can be taken up by plants. Iron, though forming but a minute proportion of the material basis of living organisms, is, nevertheless, indispensable for the maintenance of life. Phosphorus is absorbed by the plant as phosphates."

Of the thirteen elements always found in protoplasm, six are more abundant. These are the ones that make up the structure of the protein and carbohydrate molecules. Carbon, hydrogen and oxygen are the only ones that are found in that part of organic foods classed as fats and carbohydrates. The protein molecule is much more complex and only empirical formulas can be given, but in these there always occur carbon, hydrogen, nitrogen, oxygen and sulphur. One of the simplest plant proteins, the crystalline vitelline of the squash is written $C_{292}H_{481}N_{90}O_{83}S_2$, while the form of the animal protein, hemoglobin, is supposed to be about $C_{712}H_{1130}N_{214}O_{245}FeS_2$. Through the foods containing these chemical elements, organisms secure most of their energy for growth and bodily maintenance. The remaining elements found in protoplasm exist in small quantities and are usually brought to the living protoplasm in the water. It may be said that carbon, hydrogen, nitrogen and oxygen are the most important of the elements found in protoplasm because living protoplasm must be constantly supplied with foods chiefly composed of them.

The chemical composition of protoplasm helps one to appreciate how the energy locked up in the various foods may yield a certain amount of energy to the protoplasm. When a chemical molecule of starch or albumin or even molecular oxygen is utilized by protoplasm, a given amount of energy is believed to be rendered available, but it should be clearly kept in mind that when these chemical bodies unite organically they do not produce a body like themselves and with properties like themselves but something entirely distinct, namely, protoplasm. This important point is further outlined under the heading, The Biological Properties of Protoplasm.

The Physical Properties of Protoplasm.—When protoplasm is studied by means of the microscope, it presents a certain appearance. This will vary with the kind of protoplasm being studied and whether it is alive or has been fixed by such chemical agents as picric acid, formalin, etc. Up to the present it has been impossible to give a single physical description of protoplasm that applies to plant and animal, muscle and nerve, or egg and gland cell protoplasm. The physical picture presented by protoplasm under different conditions of activity and in different organisms has been accounted for by the two following theories:

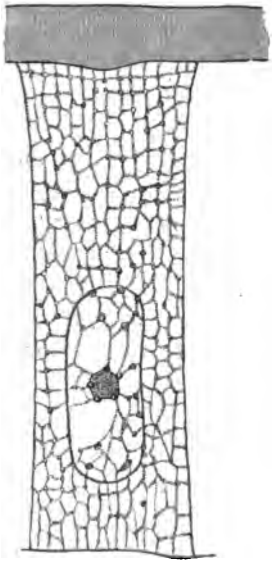


FIG. 97.—Epidermal cell of an earthworm. × 3000. (After Hall.)

1. *Fibrillar Theory.*—The adherents to this theory claim that a distinct meshwork of cytoplasmic fibrils can be made out when suitable treatment is employed and such terms as spongioplasm, reticulum, filar substances, etc., are used to describe the meshwork. Filling in the meshes there is a structureless sap-like substance. For some cells and for certain phases of cell activity the fibrillar theory adequately describes the structural conditions of the protoplasm.

2. *The Alveolar Theory of Bütschli.*—This theory assumes that protoplasm consists of two fluids, one suspended in the other. The fluid that is suspended is made up of numerous minute drops which give the appearance of closed chambers or alveoli. The containing fluid is continuous and would occur between these minute alveoli. By mixing rancid oil with sodium carbonate a solution is produced that

imitates the appearance of protoplasm very closely. The epidermal cell of an earthworm (Fig. 97), is an illustration of alveolar cytoplasm.

In nearly all forms of protoplasm, there are variously shaped granules which are the usual particles seen by students. Some of these become so large as to be the most conspicuous physical feature (Fig. 98). We may say that protoplasm consists of an aggregate of fluids which vary in density and which present a wide variety in appearance.[1]

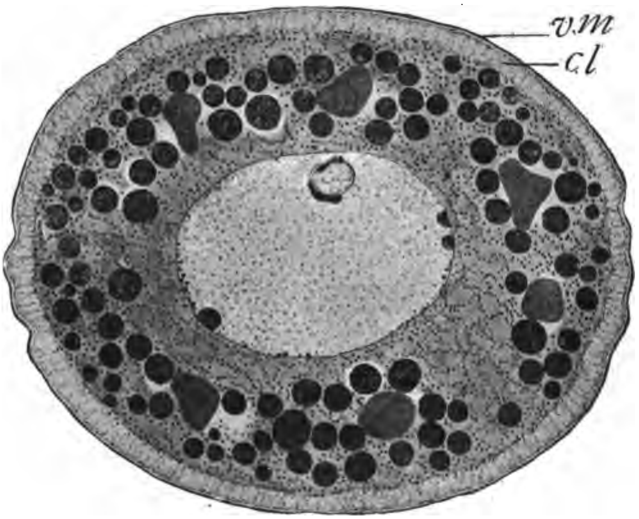


FIG. 98.—Section of the egg of *Nereis*, fixed in Meves's fluid five minutes after insemination. The cortical layer is somewhat reduced. *c.l*, cortical layer; *v.m*, vitelline membrane. Note the several kinds of bodies in the cytoplasm. (From Lillie, in Journal of Morphology.)

The Biological Properties of Protoplasm.—Neither the chemical composition nor the physical appearance of protoplasm furnishes an explanation of living protoplasm. As already stated, when chemical bodies unite to form protoplasm, there is produced a substance which has certain properties or characteristics that enable one to distinguish between that which is alive and that which is not. These are defined under the following nine headings:

1. *Relation of Life to the Living Body.*—Life does not reside in any one structure in the body of plants and animals but is present in all of their parts. It cannot be measured, photographed nor weighed. Even a child can tell a dead animal from a live one, but no one can

---

[1] For a recent discussion of the relation of colloids to protoplasm, read Matthew's Physiological Chemistry, chapter V, page 190.

isolate that which makes an organic being living. This general, diffused, immaterial condition, life, may be driven from the organism by a multitude of causes and leave all of the parts intact as when life was present—in some instances the several parts may remain alive for hours or days after life has departed. This is well illustrated by taking the heart of a frog from the recently chloroformed animal and placing it in salt water. The heart now begins to beat in a

Fig. 99.—Redwood trees in the foreground with sugar pine, bull pine and white fir in the background. Sierra National Forest, California. The redwood trees are the oldest and largest living things known to science. Illustration furnished by the United States National Museum and published with their permission.

rhythmic fashion. Living cells can be taken from various animals and when placed in an artificial culture can be kept alive for months at a time. Under such conditions they are entirely separated from the living animal; and, while able to grow under this abnormal condition, they cannot give rise to a new individual like the animal or plant from which they were taken.

2. *Size of Living Bodies.*—The size and shape of living bodies cannot be stated in any general expression. Some are so small that the highest power of the microscope has failed to reveal them, while the giant redwood trees tower above all other living things by many feet (Fig. 99). Between these two extremes are found a multitude of sizes each of which is characteristic for a given species. Animals have never grown to such large size as some of the trees, although some of the fossil forms were nearly one hundred feet long (Fig. 100). When a given kind of plant or animal comes to have a certain size and shape, there are only minor variations from year to year, as both appear to have become fixed for a given species and are continued from generation to generation by heredity.

3. *Age of Living Bodies.*—A number of the unicellular organisms retain their individuality for not more than thirty minutes under normal feeding conditions (Fig. 93); while the great redwood trees have retained their individuality for possibly twenty centuries, and between these two extremes are to be found all gradations. It is customary to speak of the longevity of a group of plants in such terms as annuals or perennials which means that certain species have come to have a certain fixed period during which they live. One of the real problems in biology is to explain old age. It is now conceded that this is a natural stage in the life of all organisms; but why should one come to have the ability to live for centuries and a closely related form but a hundred years? All organisms pass through three stages, youth, maturity and old age which are intimately associated with organic maintenance, but even when the body is supplied with suitable food, it grows old.

4. *The Cell and Living Protoplasm.*—The accumulated observations of all of the scientists clearly demonstrate that life is to be found only in protoplasm; and also, that this protoplasm is always to be found existing in structures of definite size and shape to which the name cell has been given (page 55). This is one of the most obvious facts thus far established in this course (see also Heredity, page 262).

5. *Reproduction and Life.*—All of the observations of man indicate that new forms of life are produced by living organisms. In so far

as the present varied life is concerned each species of plant and animal is produced by parent forms of the same species. Reproduction, while a universal process in life, has become highly specialized, so that only a frog can come from frog eggs and Rana pipiens cannot be derived from Rana catesbiana, although both of these frogs belong to the same family, the Ranidæ (page 21).

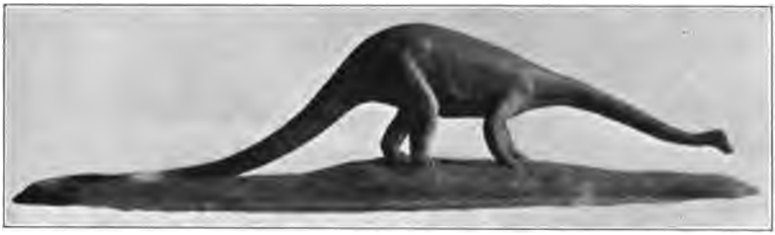


FIG. 100.—Diplodocus carnegii Hatcher, from modelled restoration by C. W. Gilmore. This reptile was probably 87 feet long and 15 or 16 feet high at the hips. One of the largest animals thus far known to science. Although this huge animal is only known through a study of its fossil remains, it can be confidently stated that it possessed all of the fundamental characteristics of modern animals. Photograph furnished by the United States National Museum and published with their permission.

6. *Growth and Life.*—Growth is one of the facts of life that all have observed. When the frog was dissected, a number of important organs were found. Where did these come from? During the embryonic growth of the frog, all of these structures gradually took shape and position in the body of the frog. Inasmuch as the term growth is used to describe the formation of crystals, it is desirable to specify its use in biology: (1) Crystals grow only in a highly saturated solution of material like the crystal itself, while living things can grow in a weak nutritive solution; (2) this nutritive solution does not contain the chemical compounds found in the living cell, while in the case of crystals, the substance of the crystal and its nutritive solution must be chemically identical; (3) growth in living things leads to the production of more living things, while growth in inorganic nature never does. Le Conte succinctly expresses this distinction in the following sentence: "It (organic life) manufactures materials like itself out of materials wholly different from itself, and then uses the product for growth."

7. *The Awareness of Living Protoplasm.*—All forms of living protoplasm respond more or less to changes in temperature like winter and summer. The habit which certain trees have of shedding their leaves is a well-known example. The small organisms react to the stimuli of

their environment in a rather definite manner as the reactions of the paramecium indicated. In the higher animals, a definite specialization in the form of the nervous system occurs which takes on the work of receiving, transmitting stimuli, and, with the assistance of the muscles producing a definite coördination (irritability, conductivity and coördination) (page 66).

8. *Maintenance of Life.* Not all young plants and animals grow to maturity nor do all adults continue to live to old age. Death is one of the most obvious facts connected with life and occurs at all ages. The keeping of the organism alive is a process distinct from growth, for it continues long after growth ceases. The technical term of metabolism (defined on page 47) is used to describe the intricate and complex changes that take place in living protoplasm as the individual organism passes from the embryo through youth to maturity and old age. Associated with the maintenance of living protoplasm is the production of those bodies to which the name of ferment or enzyme has been given.

The Fate of Dead Organisms.—Ultimately all forms of life die, and yet the surface of the earth is not cumbered with them as would be the case if they remained intact after death. The group of organisms included under the heading Ferment Organisms, particularly the saprophytes, begins to tear down the substance of these dead bodies and this continues through a longer or shorter time until there exist a number of free chemical elements in the place of the organism. The substance of the dead organism has been returned to nature and the chemical elements have been released and set free. This fact when taken with the above distinctions of living protoplasm constitute one of the important characteristics of life. None of them have been destroyed, and all of them are available to be used by some form of life. It is thus seen that the elements that enter into the living protoplasm pass through a fairly regular cycle. No one can tell how many times the oxygen that we are breathing has been a part of other living things nor for how long a time. All that we know is that it is useful to us. It does not matter how often nor how long an element is used so far as its usefulness to future living things is concerned, provided it is properly combined so that the plant or the animal protoplasm of perhaps a thousand years hence can utilize it. We may feel then that there will always be plenty of the necessary chemical elements to support life, because living matter does not destroy them and cannot exhaust them, but simply holds them in the living relation for a longer or shorter period.

Life or living protoplasm is thus seen to be composed of certain limited chemical elements having a characteristic physical appearance. The biological properties are distinctive for matter in the living condition and are not found united in any of the inorganic bodies. Any new creation of life that may be announced from time to time must have all of these characteristics, if it is to be identified with the life which now exists. With the great amount of specialization that is being carried on, it is pertinent to urge that life should be studied as a whole and not as so many parts, for it is really the whole life that determines the several parts. It is also desirable to urge that for the biologists LIFE is the fundamental reality and not the physics or chemistry of it.

REFERENCES.

Bütschli, O.: Investigations on Microscopic Forms and on Protoplasm.
Haldane, J. S.: The New Physiology, Science, 1916, p. 619.
Osborne, H. F.: The Origin and Evolution of Life.
Spallangani, Foster: Lectures on Physiology.
Tyndall: Floating Matter of the Air.
Vallery-Radot: Life of Pasteur.

CHAPTER XII.

SOME LOWER PLANT TYPES.

Thallophytes.—Probably the most important thing about a plant is the way that it gets its food. The normal plant, whether it be simple or complex, is one that can gain its food from nature. It is not a dependent organism. To this fundamental conception in regard to the nature of a plant should be added another, namely, that there has been an evolution in plants along divergent lines resulting in the formation of plant groups in which the genetic relations are complicated. In this process of evolution, however, some of the structural characters of the simple plants are to be found in the higher, although greatly modified.

In the thallophyte phylum are placed the simplest forms of plants, The body is a thallus and there is no root, stem, or leaf in the usual sense. The cells of the plant are similar and tissues are absent except as noted below. In some members of this group root-like processes, known as holdfasts, are developed. Many of these plants are fragile, having the cells united into a linear series, while others are like the brown kelp, tough sea-weeds, many feet in length.

As the classification indicates the thallophytes are composed of many normal chlorophyll-bearing plants, the algæ, and the divergent and dependent group of fungi, many of which show definite algal affinities. The fungi live as parasites, saprophytes, and symbionts, and their relations to disease in plants and animals is so important that a separate course is necessary to present even the general facts of disease in fruits, in grains, in trees, in domestic animals, and in man.

The life cycle of this group is relatively simple as compared with the remaining phyla of plants, and this serves as their chief distinguishing character rather than the nature of the thallus. For some of the higher plants have thalloid bodies and some algæ have a stem-like and leaf-like structure as complicated as that of mosses, and a well-defined system of tissues. This group, then, is especially interesting because it shows the beginning of tissue differentiation and the origin and earliest expression of sex and sex organs.

CHLOROPHYCEÆ, THE GREEN ALGÆ.

This is the largest class of the algæ, containing more than 8000 species. They are found in both salt and fresh water as well as on land. Of the simpler plants, several members of this class are among the most common. The familiar "pond scum" or "frog's spittle" in the ponds and slow-running streams as well as the green covering on moist surfaces of the earth, in pots, etc., called "green felt" are two of these plants that are first learned. The former is some form of spirogyra and the latter vaucheria.

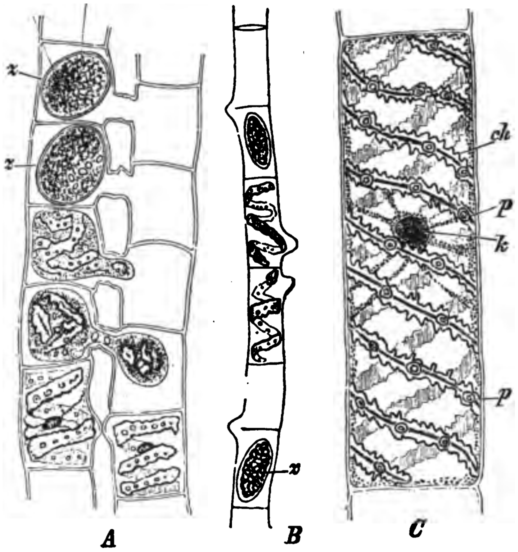


FIG. 101.—*A*, conjugation of *Spirogyra quinina; B, Spirogyra longata; C*, a cell of *Spirogyra jugalis; ch*, chromatophore; *k*, nucleus; *p*, pyrenoid; *z*, zygospore. (Strasburger, Noll, Schenck, and Karsten.)

Spirogyra.—"Pond scum" consists of many long, silky threads. Each thread is a complete plant of several cells attached end to end. The green color varies. Each cell of spirogyra is large and cylindrical in shape. In each cell there are one or more spirally arranged bands containing chlorophyll; these are the chromatophores or chloroplasts; their number and their manner of coiling depends upon the species. The cytoplasm is distributed in the cell as a thin layer next to the cell wall. Fine threads of cytoplasm extend from all sides to the nucleus. The center of the cell is occupied with sap.

In the chloroplasts are several pyrenoids which are the special centers where the starch is manufactured (p. 99). Spirogyra is composed of nearly 98 per cent. water, and yet the vital processes of the plant are adequate to enable it to manufacture food. The masses of spirogyra are frequently full of bubbles of oxygen that are given off in this vital process.

Spirogyra reproduces by normal cell division, and the new cell wall forms at right angles to the length of the filament. Such divisions cause the filament to increase in length. This form of cell division takes place very rapidly. The second form of reproduction is important because it illustrates an early stage in the development of the sexual method. The cells of two plants that lie near together form connecting bridges (Fig. 101, *A*), which are tubular outgrowths that eventually furnish a continuous passage between the connecting cells. The protoplasmic contents of one cell flow into the other and the two masses unite into a single body which has become much reduced in size. A thick cell wall is secreted around this body, which is termed a spore. In view of the fact that the masses were formed by the fusion of similar cells the spore is called a zygospore (a yoked spore). The two protoplasmic masses that fused are called gametes. "Cells that unite to form sex spores are called gametes; hence, a zygospore is a sexual spore that is formed by the union or conjugation of similar cells." As the parent plants decay, the zygospores escape. A period of rest follows, caused by a drought or winter, after which each one begins to grow into a new spirogyra. The formation of this reproductive spore is of obvious advantage.

Vaucheria.—This is the common "green felt" which is usually found growing on the soil, although it may be found in the water. The filaments are coarse, much longer than spirogyra and branching. Plants taken from the soil usually penetrate it slightly. The youngest branches are the greenest. The whole filament consists of a single cell with numerous nuclei scattered throughout its length. This arrangement may have arisen through the failure of the dividing cell to form walls. Such a condition is termed a coenocyte or syncytium. The cytoplasm of vaucheria contains numerous chloroplasts which indicates that it has the power to manufacture an abundance of food.

Asexual reproduction accidentally takes place when the old end of the filament dies and as it decays sets free the branches which now become separate plants. Asexual reproduction normally begins by the formation of a cross wall in one of the branches. The isolated protoplasm becomes transformed into a large zoöspore (Fig. 102). This body escapes into the water and swims about for a time then grows into a new vaucheria. The zoöspore is made up

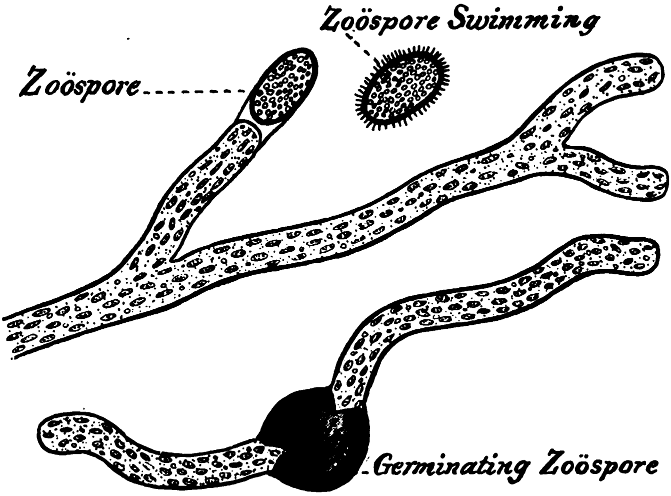


FIG. 102.—Vaucheria—asexual reproduction.

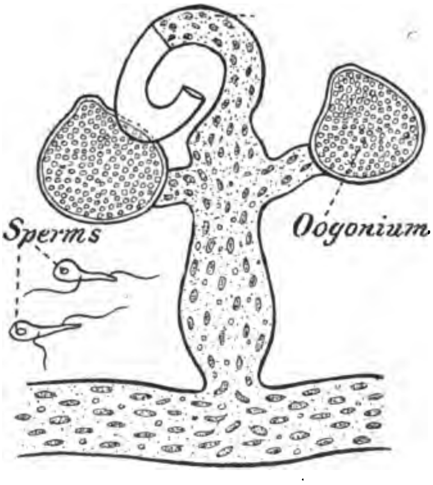


FIG. 103.—Vaucheria—sexual reproduction.

of many cells, although it gives rise to but one plant. Sexual reproduction occurs through the formation of special short branches on the side of the plant (Fig. 103). On this branch one or two large oval masses appear with a beak-like process. The terminal branch in the figure is long and coiled with a terminal cell cut off from the rest of the branch. In this terminal cell many small cells are formed which escape into the water. By means of long cilia they are able to swim about. One of these cells enters the oval mass. After the union of the two gametes, a thick wall is formed about the cell which is called an oöspore; after a period of rest it grows into a new plant. The only difference between this process in vaucheria and the conjugation in spirogyra is in the unequal size of the uniting gametes.

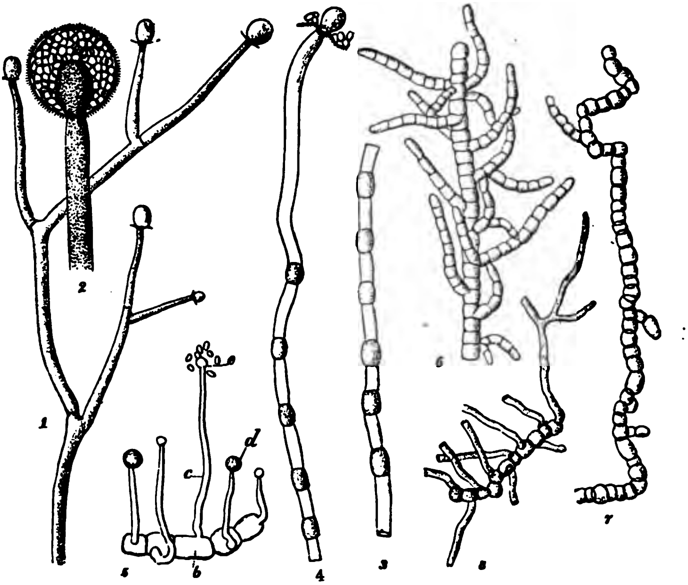


FIG. 104.—Development of lower fungi: *1*, branched filament carrying spores; *2* cross-section of spore highly magnified; *3* and *4*, spore building; *5*, developing and bursting spores; *6* and *7*, branching; *8*, sprouting spores. (After Tazel.)

The large oval mass that receives the small free-swimming gamete is now called an egg or oösphere; while the small free-swimming gamete is a sperm. *The union of the sperm and egg is fertilization.* The special cell which produces the sperms is termed the antheridium; while the cell that produces the egg is the oögonium.

PHYCOMYCETES, THE ALGÆ FUNGI.

The general subphylum of fungi includes one of the largest groups of plants: there are more than 64,000 known species.

The general habitat of this group is well expressed by Underwood as follows: "Whether we are aware of their existence or not, there are in the world about us a vast array of more or less inconspicuous organisms that are known to botanists under the name of fungi. These differ among themselves in size and structure far more widely than do a violet and an oak, and many of them at first sight would seem to bear so little resemblance to one another as to possess no real relationship. Many of them are known more or less popularly under common names, such as moulds, mildews, mushrooms, toadstools, puff-balls, rusts, smuts, leaf spots, and blights, each popular name indicating a more or less indefinite group of plants more or less closely related to one another. They grow in every conceivable place where organic matter can be found which will serve as their food, and a moderate degree of heat and moisture are present to furnish the necessary conditions of growth. Decaying fruit or vegetables, oily bones, old musty shoes, wet paper, the dead stems of herbaceous plants and woody plants, the dead and dying branches of trees, standing stumps and tree trunks, and fallen logs all furnish the matrix in which fungi of various sorts, a few conspicuous, many more inconspicuous, thrive and multiply. With all their differences fungi agree in two characters: (1) No chlorophyll. (2) They reproduce by spores. In the many different substances enumerated above, all are the product of some form of organic activity. This permits the habitat of fungi to be subdivided into (1) those that live upon dead organic matter and are called saprophytes and (2) those that subsist upon living organisms and are known as parasites."

The algæ fungi, as the name suggests, are fungi which are similar to algæ. The well-known bread mould illustrates some of these similarities.

The Bread Mould is a common form of one of the simple moulds that grow in abundance in our homes upon bread, fruit, and other suitable substances. It consists of a tangled mass of thread-like structures which is the main working body of the plant. The name mycelium is given to the interwoven mass which may become quite compact in older growths. The individual threads are called hyphæ. Some of the hyphæ send out special threads, which are known as rhizoids, which penetrate the nutrient material. The bread mould derives its nourishment directly from the nutrient substances upon and in which it is growing. We may believe that the foods found in the bread are utilized through the production of certain enzymes by the hyphæ. The reason for believing that this is the method is because *Aspergillus niger,* a mould, has the reputation of forming a large number of enzymes; and *Pencillium camemberti* (the chief organic agent in ripening Camembert cheese), according to Dox, produces the following enzymes: erepsin, dulclase, aminase, lipase, emulsin, amylase, inulase, raffinase, invertase, maltase, and lactase. The formation of the mycelium takes place by the asexual or vegetative method of reproduction. After a time a number of upright stalks are produced from the mycelium and are called sporangiophores (sporangium bearers). The tip of each upright branch produces a globular sporangium which is full of spores. The walls of the sporangia burst and the dust (spores) is scattered by air currents.

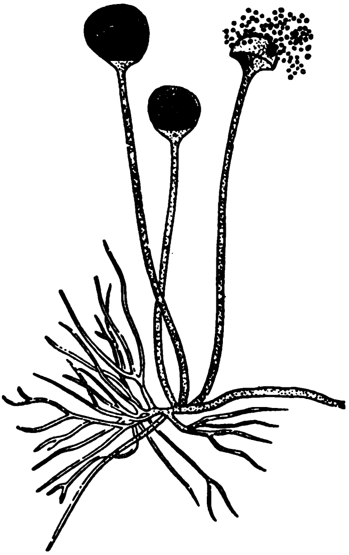


Fig. 105.—Bread mould.

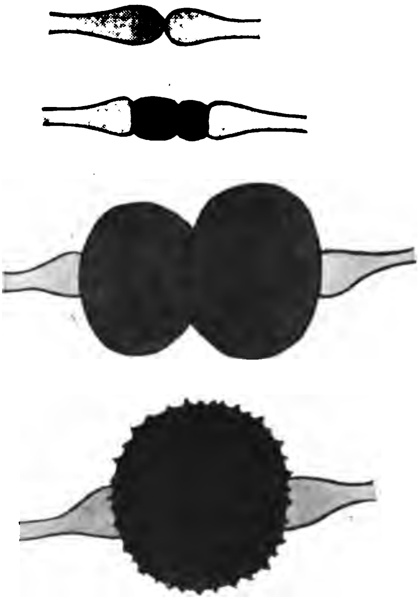


Fig. 106.—Mucor spore formation.

When the bread mould reproduces by the sexual process, which it does rarely in nature, the process is interesting because it is so similar to spirogyra. The free ends of two hyphæ come in contact (Fig. 105), and end cells are cut off. These two end cells enlarge and eventually unite to form a single spore with a dark heavy wall (Fig. 106). The two cells which contribute to the formation of this spore are similar, and so the resulting body is a zygospore.

Water Moulds.—There is one very common water mould which lives upon dead insects, fish, and other animals. This mould has the interesting habit of thriving either on a dead fish or one that is alive, readily assuming either the saprophytic or the parasitic habit. At times it becomes a serious pest in fish culture. A culture of water mould (saprolegnia) is usually secured by simply dropping a dead fly found on the floor or window sill into a dish of water. There is soon formed a whitish mass of hyphæ growing out in all directions from the insect. The hyphæ on the body of the insect digest such parts as may serve as food, and it is in this way that they are effective agents in destroying dead animals in the water. The water mould reproduces by the asexual and sexual methods. The water and bread moulds serve to illustrate a type of plant life that has its food already made; they are plants related to certain green plants and they differ from them chiefly in the absence of chlorophyll. This suggests that the habit of utilizing ready-made food is really an acquired habit. More or less closely related to these common moulds are the mildews, rusts and many others less well known.

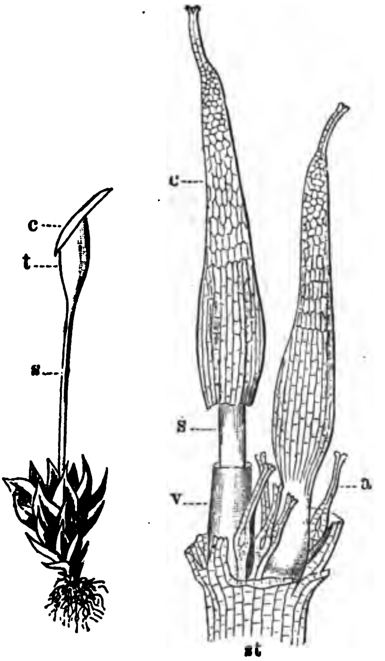


Fig. 107.—Showing the development of sporophyte of moss. *st*, apex of stem, bearing the female organs; *a*, the archegonia; from these, after fertilization, the young capsules spring, *c*, *s*, *v*; *c*, the calyptra underneath which is found lid or operculum; *t*, the capsule; *s*, the leafless stem of sporophyte or pedicle. (Frank.)

Bryophytes.—The life cycle of this phylum is more comprehensive, for there are introduced two stages—the sexual and sexless. This means that in the life cycle of every liverwort or moss two distinct phases of the plant play alternating parts. The sexual plant (gametophyte) contributes eggs and sperms and secures the fertilization of the egg; the other, the non-sexual (sporophyte) generation, is produced by the fertilized egg and in turn contributes non-sexually formed spores from which the sex generation takes its origin. This process is termed alternation of generations. In the simple bryophytes the sex plant is thallus-like, but this is a plant with a leafy stem in the mosses. The sexless plant begins as a simple structure that gradually develops into a complex plant bearing an elaborate spore case. The sexless plant lives as a partial parasite upon the sexual plant. In all instances the sexual organs of the bryophytes are many-celled structures, while those of the thallophytes are almost always one-celled.

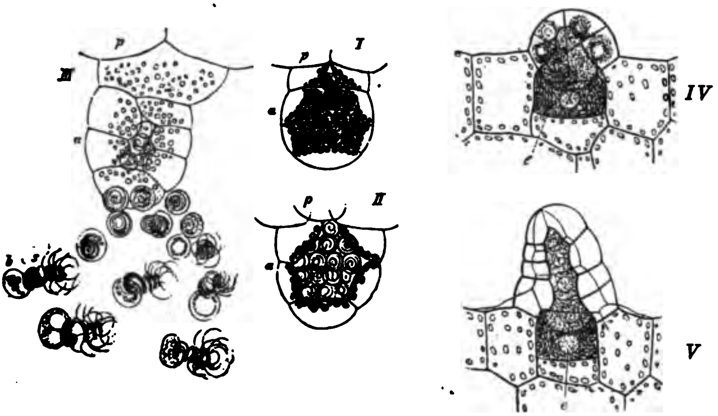


Fig. 108.—Sex organs of the ferns; *I, II, III*, stages in the development of the male organ, or antheridium; *p*, cells of the prothallium or gametophyte. In *III* are shown the mature sperms, which are provided with cilia; *IV, V*, stages in the development of the female sex organ or archegonium; *e*, oösphere or egg cell. (Rusby.)

The plants of this group show on the whole a more complete differentiation of the cells into tissues and in the higher forms leaf-like and stem-like structures appear. Specialized absorbing organs, the rhizoids, are developed and the plant tissues contain chlorophyll. The evolution of the bryophytes is closely associated with the change from the aquatic to the land habit. Here the parts of the plant become exposed to the drying effects of the air which require important structural adaptations. These differentiations foreshadow the general plan of structure of the higher plants.

Pteridophytes.—"The pteridophytes undoubtedly arose from a bryophyte ancestry where the sporophyte (sexless) generation, in some plants capable of doing chlorophyll work, developed a root system and vascular tissue, and taking the land habit, became independent of the gametophyte. This was one of the most important forward steps in the evolution of the higher plants, for it gave the sporophyte complete freedom to live and grow to its maximum size. This change marked a turning-point in plant evolution, for after the sporophyte became the most complex and conspicuous phase of the life-history the gametophyte grew less prominent, until in the seed plants the sexual generation became actually dependent or parasitic upon the asexual generation. This is a relation which is exactly the reverse of that which exists between the gametophyte and sporophyte in the liverworts and mosses."

"After the sporophytes became independent of the gametophyte, the next important advance was the development of the lateral spore-bearing and vegetative organs called fronds. Then came the differentiation of the frond into vegetative leaves, given up entirely to chlorophyll work, and spore leaves (sporophylls) devoted chiefly or wholly to spore production. With this also came the massing of the sporophylls in cones, which was really the beginning of the structures called flowers in seed plants."

In the simple ferns the sexual plant is a thallus-like structure bearing both antheridia and archegonia, and growing in such situations as to enable the sperms to utilize the water as a means of reaching the eggs. In some of the higher members of the phylum, such as Selaginella and Isoetes, large and small spores, called respectively megaspores and microspores, are produced. The megaspores produce sexual plants which bear only archegonia, or female sex organs; these sexual plants are therefore called female gametophytes. Similarly the microspores produce only male gametophytes. In plants producing the two kinds of spores, the sexual plants are more or less mechanically retained within the tissues of the sexless plant and much degenerated, thus foreshadowing the condition in seed plants, but even in this relation water is the agency which carries the sperm to the egg.

Spermatophytes.—The division spermatophyta (meaning seed plants) contains not only the groups frequently called "flowering plants" but also other groups which do not have flowers, for the reproductive organs are borne in cones or clusters which are not at all showy, but rather inconspicuous. The spermatophytes have also been called phanerogams (meaning evident marriage), to distinguish them from all the lower groups of plants which are called cryptogams (meaning hidden marriage). However, this separation was made before the sexual processes of the lower plants were understood, for as a matter of fact they are much more evident than the complicated ones in the seed plants. The seed is a more significant structure in the group than the flower, so the name spermatophyte has in recent years come into general favor. The seed plant, like the fern, is a sporophyte. There is a gametophyte generation in the life history, which is, however, so much reduced in structure that it can only be understood by a careful study of the reproductive processes in seed formation.

The Seed.—"The importance of the seed in the development of plant and also of animal life can hardly be exaggerated. For the plant it furnishes one of the surest means of reproduction not only because of protective structures, means of dispersal, long vitality, etc., but also because the embryo plant is carried so far forward in its development that it is able to take root and establish itself at once. And further to aid the embryo, the seed is a storage organ of the most condensed forms of food material found in plants. In this respect, also, the seed has proved a most important influence in shaping the habits and in a large measure the evolution of some forms of animal life; for the highest groups of animals live to a very great extent directly or indirectly upon food stored in seeds and certain fruits, finding there some of the richest and most nutritious proteid and carbohydrate foods." (Bergen and Davis.)

The pollen grain of seed plants corresponds to the microspores of pteridophytes, and produces a male gametophyte which bears sperm cells. Similarly, within the ovule of the seed plant occurs a cell which corresponds to the large spore (megaspore) of pteridophytes and which produces the embryo sac in which the egg is formed. In order that fertilization may take place, the pollen grain produces an outgrowth or pollen tube which penetrates the tissues surrounding the egg and carries the sperm cells to the egg.

The spermatophyta have the most perfect expression of root, stem, and leaf found in any plants. It is but a short process to perfect the formation of the seed already anticipated, and so the members of this group have become differentiated in solving the life-cycle problem with the result that they have expanded into a multitude of forms following two lines of evolution, one the monocotyledons in which the cat-tail flag may be thought of as the lowest and the orchids as the highest; and the dicotyledons, in which a similar primitive and recent display is represented by such plants as lizard's tail and the crowning group of composites.

CHAPTER XIII.

AN ANGIOSPERM—TRILLIUM GRANDIFLORUM.

Trilliums.—The common trilliums belong to the family of plants known as the Liliaceæ, which includes some 2500 species that are widely distributed and extensively cultivated. Among the cultivated species that are familiar are the hyacinths, lilies, tulips, lily of the valley. Asparagus and onions are lilies cultivated for food and the aloes, colchicum and others are used in medicines.

There are several species of trilliums in the Unites States, of which the wake robin (Trillium grandiflorum) is the commonest. Its natural habitat is in or near the woods where it is frequently found with the painted trillium. Fig. 109 gives a good idea of the habitat of the trilliums.

The entire plant consists of a thick, fleshy, underground stem or rhizome from which arise numerous, strong, wrinkled roots; and a leafy flowering stem bearing leaves and the flower. The rhizome lives on for a number of years and so is termed perennial. It is marked by ridges and scars which indicate something as to its age, since each scar indicates where a single flowering stem was attached. The new leaf stalk arises from the growing end each year. The leaf stem normally bears a whorl of three sessile leaves near the flower. From the center of this whorl arises the flower stalk bearing a flower at its summit (Fig. 110).

The flower is the most conspicuous feature of the higher plants. It has passed through many evolutionary stages before we come to the highly developed flower of the trillium. The parts of this flower are the calyx, the corolla, the stamens, and pistil. The calyx consists of a whorl of three pointed, green, leaf-like structures. Each individual part is called a sepal. The calyx is thus seen to be made up of three sepals, which are easily recognized as similar to the leaves. While the corolla is made up of structures similar to the sepals, they are wider and white in color. Each member is termed a petal. Within these two whorls of leaf-like structures are found two whorls of much smaller parts, the stamens. Each stamen consists of a stalk or filament bearing an enlarged part called the anther. Each anther consists of four sacs which fuse into two as the contents become mature (Fig. 112, *C*). These sacs contain a quantity of yellowish spores which are the pollen grains. In the center of the flower is the stout, angular pistil which terminates in three long, slender, curved points (Fig. 112, *A*). On the inner surface of each of these points is a roughened area that is sticky; these are the stigmas of the pistil. The base of the pistil contains a three-lobed chamber (Fig. 112, *B*) in which are many ovules.

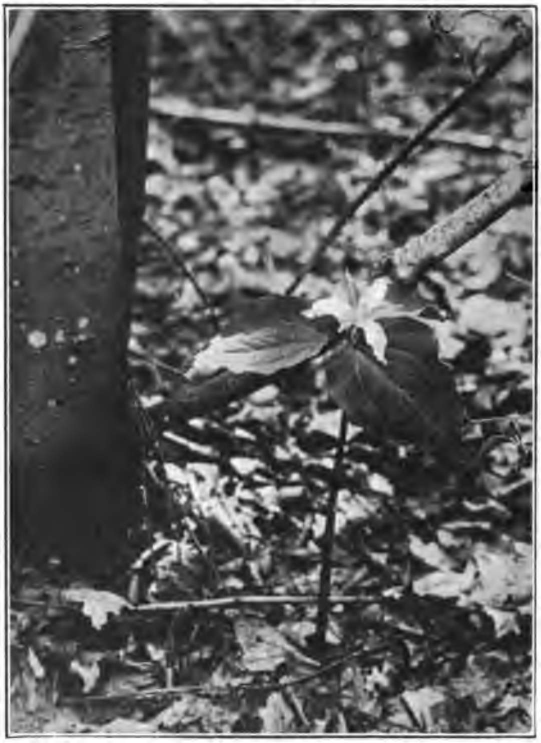


Fig. 109.—Painted trillium.

Study of the development of the stamens of flowers has shown that they are modified leaves; similarly, the pistil in trillium is composed of a group of three modified leaves called carpels.

In trillium the sepals and petals are very much like leaves, but one does not see the superficial resemblances as readily in the stamens and pistil. The development of these two organs, however, leaves no doubt as to their origin. The writer found striking confirmation of this theory in nature. The trillium shown in Fig. 111 showed

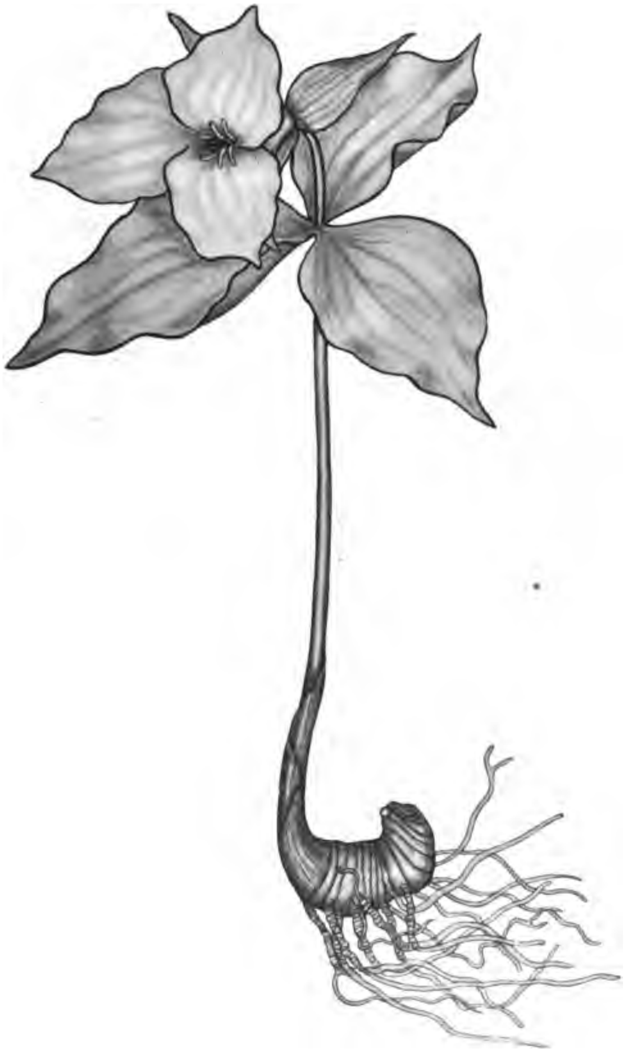


Fig. 110.—Trillium grandiflorum.

basal leaves with long petioles, and sepals and petals both green and similar to the leaves. But most significant of all was the condition of the stamens and pistil. Each of these organs of the flower was

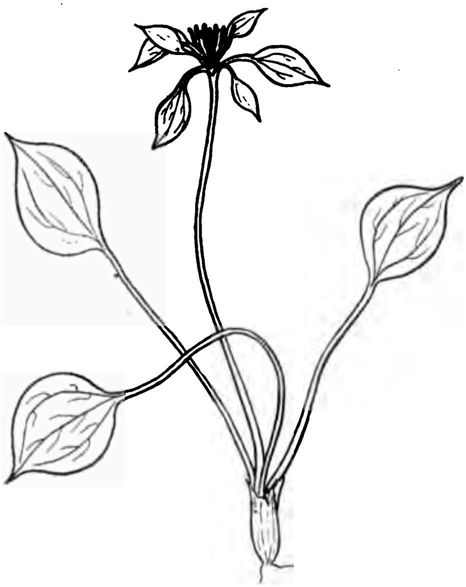


Fig. 111.—Trillium grandiflorum.

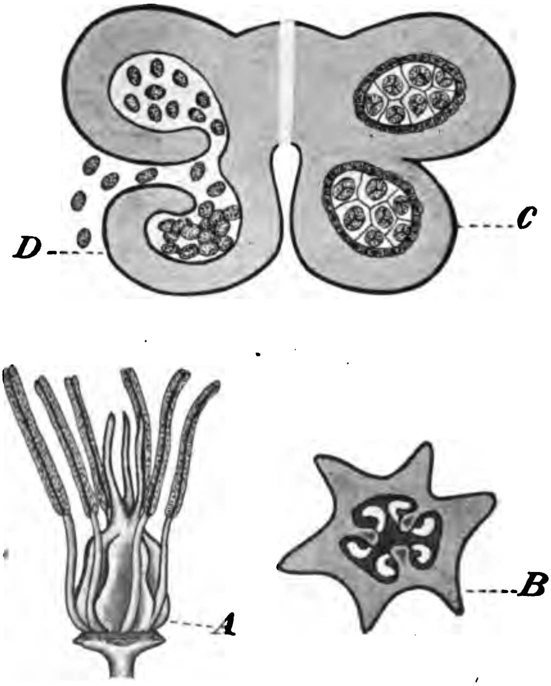


Fig. 112.—*A*, stamen and pistil of trillium; *B*, cross-section of the ovary, showing ovules; *C* and *D*, cross-section of anther; *C*, young anther, showing formation of pollen grains; *D*, mature anther.

green in color, all were supported on stalks similar to the leaf petioles, while some of the stamens were broader than the normal stamens.

The structure of the flower stem shows that there is a definite number of tissues each with its own work to do. On the outside there is an epidermis of one layer of cells which is protective; inside of this are one or two layers of a thick-walled tissue also protective in function. A thin-walled tissue, the pith, makes up the bulk of the whole stem; and scattered in the pith are numerous fibrovascular bundles. The detailed structure of a fibrovascular bundle in trillium is shown in Fig. 113. In the leaves the veins are the fibrovascular bundles and the epidermis tissue becomes differentiated into an upper and a lower epidermis (Fig. 114). The under surface of the leaf is furnished with stomata which regulate the outgo of moisture from the leaf. The interior of the leaf is composed of cells which contain many chloroplasts. In the chlorophyll bodies the carbohydrate food of the plant is made (see page 99). While carbon forms nearly one-half of the dry weight of plants yet all of this carbon is

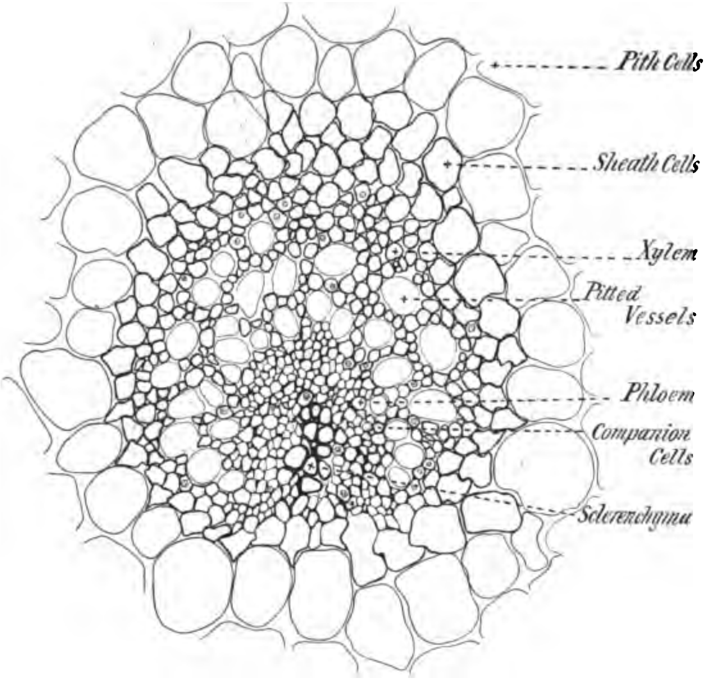


FIG. 113.—Fibrovascular bundle of trillium.

derived solely from the carbon dioxide in the air. It is estimated that a square meter of leaf surface can draw all of the carbon dioxide from 2500 liters of air in one hour. This furnishes sufficient carbon for the construction of one gram of starch. The food made in the leaf is transferred to all parts of the plant. The phloem cells in the fibrovascular bundle carry the food, while the water travels in the xylem strands. All excess of food is stored in the underground stem. As the food circulates through the plant, it is absorbed by the cells and utilized in the life processes of the plant. The principles of digestion are the same as for the frog. A plant protein is non-diffusible and must be rendered diffusible. Digestive enzymes prepare the plant food for the cells.

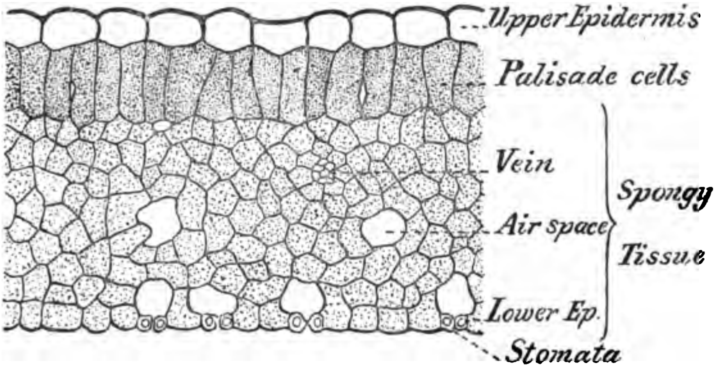


FIG. 114.—Section through lily leaf.

The young flowers of trillium begin their development in June or July and by autumn are well formed, though they remain protected by the sheathing bud during the winter, and blossom in the early spring. The tips of the plants appear above the ground about the middle of April and the flowers are usually in full display by the first of May in central New York. Since the structures and processes concerned in the reproduction of flowering plants by seeds are essentially the same for all species, a general account of these structures and processes is given here.

The pollen grains are formed in the anther while the flower bud is still very small—in trillium at about the time that the shoots come above the ground. The pollen grains are single cells, usually with thick, roughened walls. They correspond to the microspores of the pteridophytes. As the flower develops, the nucleus of each pollen grain divides, forming two cells, known respectively as the generative cell and the pollen tube cell (Fig. 115, *3*); this is the condition of the pollen in the mature flower.

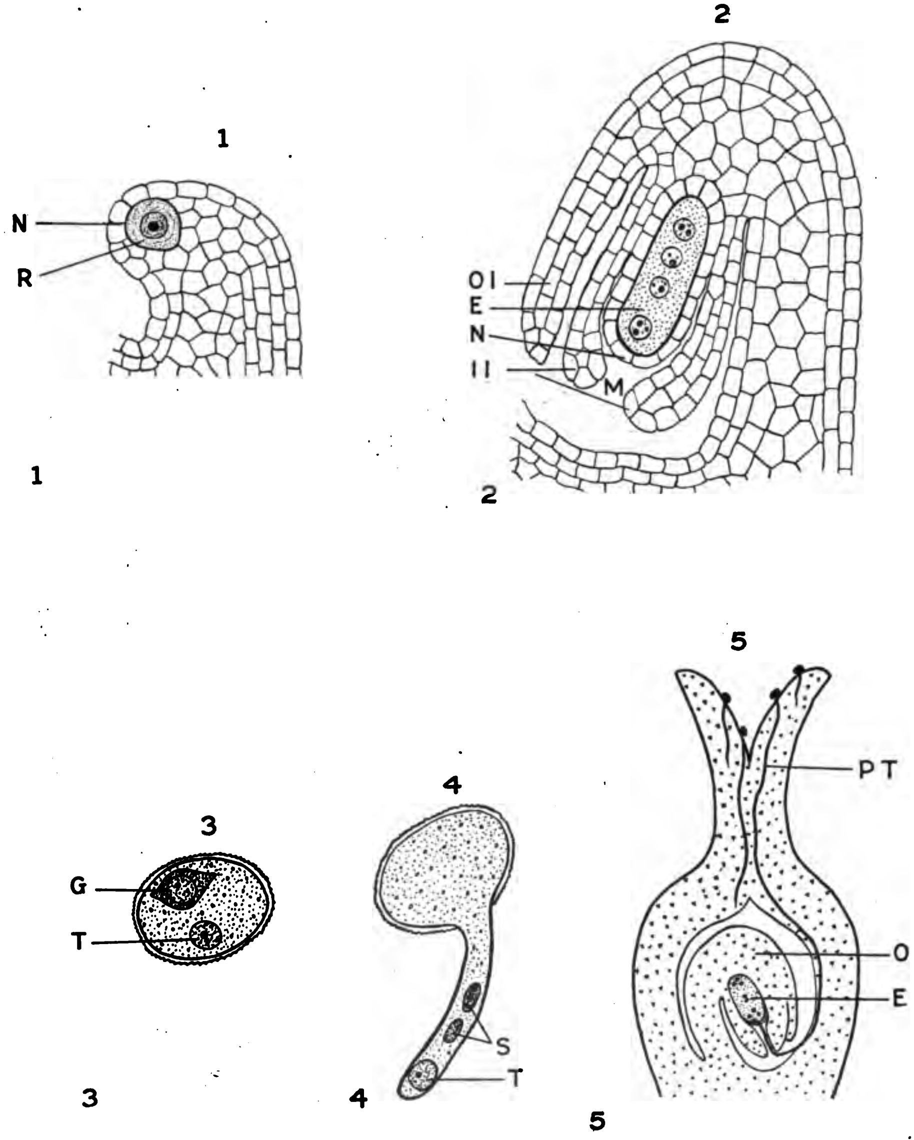


FIG. 115.—*1*, young ovule of *Lilium*. *N*, nucellus; *R*, embryo sac mother cell. *2*, older ovule; *E*, embryo sac; *II*, inner integument; *OI*, outer integument; *M*, micropyle. *3*, pollen grain of *Lilium*; *G*, generative cell; *T*, tube nucleus. *4*, growth of the pollen tube; *S*, sperm cells. *5*, diagram of pistil, showing the course of the pollen tube; *O*, ovule; *PT*, pollen tube.

The ovule first appears as a projection on the inner wall of the ovary. Within the ovule is a large cell which may be called the embryo sac mother cell, and is the equivalent of the megaspore of the Pteridophyta. This cell is contained within the nucellus; as the ovule develops, two protective layers, the integuments, develop about the nucellus, but never entirely enclose it. The small opening that is left is the micropyle (Fig. 115, *1*, *2*).

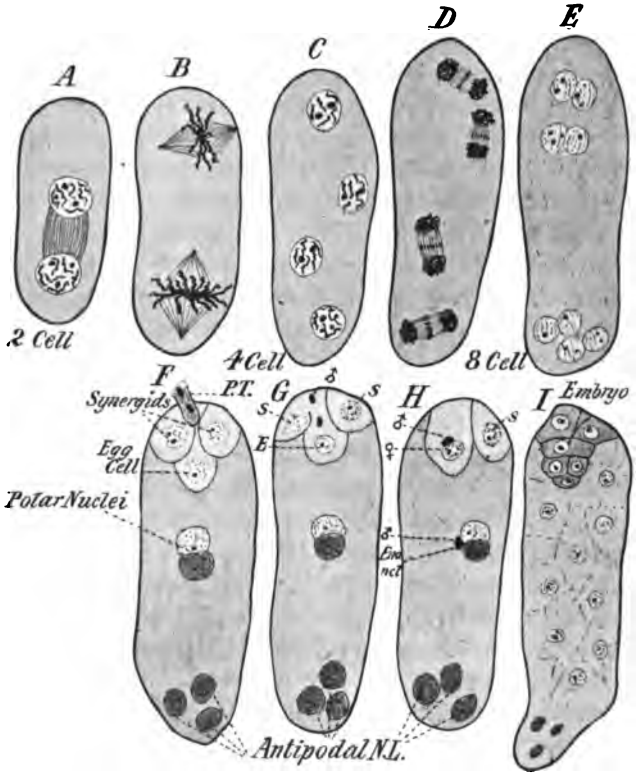


FIG. 116.—Development of the embryo sac of seed plants. *P.T.*, pollen tube. (Redrawn from Coulter.)

As the flower grows the ovule enlarges and the nucleus of the embryo sac mother cell (Fig. 115, *R*) divides. The two daughter nuclei then divide simultaneously, producing four free nuclei (Fig. 116, *C*); another simultaneous division occurs, producing eight nuclei which collect in two groups of four each in the ends of the greatly enlarged embryo sac (Fig. 116, *D*, *E*). Delicate membranes occur about three of the nuclei at the end of the embryo sac toward the micropyle, forming a group of three naked cells known as the egg apparatus. The two lateral cells are the synergids; this term means "helpers" and indicates that they are supposed to assist in fertilization. The cell between the synergids is the egg; it is often somewhat larger than the synergids. Three of the nuclei at the opposite or antipodal end of the embryo sac remain for a time unchanged or in some instances organize cells by the formation of delicate walls; in any case they eventually degenerate. The remaining two nuclei, one at either end of the embyro sac and known as polar nuclei (Fig. 116, *F. G, H*) move through the cytoplasm toward the center of the sac and come to lie in contact with each other. This entire structure of eight cells, one of which is an egg, is a sexual phase of the life history of the plant, the female gametophyte. It reaches this mature condition in the fully opened flower.

Pollenization is the transfer of pollen from the anther to the stigma of the pistil. It may be brought about by many agencies, such as wind, insects, and even water, as in the case of some plants with submerged flowers. Of these agencies, the wind is most important in the simple flowering plants, such as willows, poplars, etc.; but in the great majority of species pollenization is effected by insects which visit the flower to secure nectar or other food furnished by flowers. In securing this food, the insect brushes against the anther and some of the pollen adheres to its body. In the course of the normal feeding of these insects some of this pollen will come in contact with the stigma of the same flower or of another of the same species, and pollenization will be accomplished.

When the pollen grain has been transferred to the stigma, it begins at once to grow, forming a tube which digests its way through the style of the pistil (Fig. 115, *5*). The nuclei of the pollen grain pass down into the tube and the generative cell soon divides into two sperm cells (Fig. 115, *4 S*). This structure of three cells is the other sexual phase of the life history, the male gametophyte. The tube continues its growth through the tissues of the pistil until it reaches the vicinity of the ovule where it turns aside and enters the micropyle. A passage is digested through the nucellus and the two sperm cells are discharged into the sac. One of these fuses at once with the egg cell (Fig. 116, *H*); this is fertilization, the sexual process involved in reproduction in seed plants, and is not to be confused with pollenization which is not sexual.

The other sperm cell moves through the cytoplasm to the center of the sac where it comes in contact with the two polar nuclei (Fig. 116, *H*). The three nuclei then fuse, forming the primary endosperm nucleus and the process is called triple fusion. This nucleus soon divides, and repeated divisions of the daughter nuclei follow, producing an extensive thin-walled tissue, the endosperm, which fills the entire embryo sac. This is a nutritive tissue and supplies food to the embryo.

The fertilized egg soon divides, forming a mass of several cells, the embryo (Fig. 116, *I*). The further growth of the embryo carries it deep into the endosperm from which it absorbs food. At the same time the integuments about the embryo sac harden and become the seed coats or testa. The embryo now stops growing and remains in a dormant condition and the seed is mature. When the seed is placed in favorable conditions of heat and moisture, water is absorbed and the embryo resumes growth; this is the germination of the seed and results in the formation of a new plant.

It is to be noted that the life history of a seed plant shows the same alternation of sexual and sexless phases that is seen in the lower groups. The ordinary flowering plant of which the trillium is an example is the sexless or sporophyte phase and the nucleus of each cell contains twelve chromosomes. This plant produces microspores, or pollen grains, and megaspores or embryo sac mother cells; in the nuclear divisions which produce these cells, the chromosome number is reduced to half its original number, that is, six in the case of the trillium. The pollen grains produce one of the sexual phases of the life history, the male gametophyte which forms sperms; the embryo sac mother cell produces the other sexual phase, the female gametophyte which bears an egg. Fertilization occurs by the fusion of a sperm cell with the egg; thus the nucleus of the fertilized egg contains twelve chromosomes, six of which have been contributed by the sperm and six by the egg. This fertilized egg develops into the embryo of the seed which, upon germination, becomes the mature sporophyte or sexless phase of the life history with its characteristic number of chromosomes.

REFERENCES.

ATKINSON, G. F.: Reducing Division of the Chromosomes in Trillium Grandiflorum during Sporogenesis, Bot. Gaz., 1899, xxviii, 10.

ERNEST, A.: Chromosomenreduction, Entwickelung des Embryosacks und Befruchtung bei Paris quadrifolia L. und Trillium grandiflorum Salisb. Flora oder Allgem. Bot. Zeitung, 1902.

CHAPTER XIV.

CLASSIFICATION AND THE ORIGIN OF MULTICELLULAR ORGANISMS.

CLASSIFICATION.

THERE are more than 47,000 known members of the true vertebrates, and when to this is added the more than 360,000 insects, the star-fishes, the molluscs, and the many unicellular forms, there is a multiplicity of animals that is truly confusing. The earliest students of zoölogy were perplexed by the confusion of numbers and attempted to work out schemes of classification. Some of these were shrewd guesses while others were errors, because men did not understand the fundamental organization of the great groups. When biologists accepted the cell theory and biogenesis, a working plan for classification was furnished, for the first shows that all forms of life have the cell as their unit of structure, and the second holds that there is a genetic relationship between all animals. Biogenesis thus becomes an important working plan in all modern attempts to classify organisms, whether it be in their arrangement into the great groups or their specific designation. Scientists are in agreement as to the limits of the great groups or phyla of the animal kingdom, but when an attempt is made to arrange these phyla in a definite sequence a difference of opinion often arises.

Each phylum is variously subdivided according to the number of animals and the definiteness of their structural differentiation. Each phylum includes a number of animals that have the group characters. This is easily illustrated in the protozoa. They are minute, mostly microscopic, aquatic, unicellular animals that reproduce by fission. Each animal to be classed in the protozoan phylum must have these common characters. The next problem is to arrange the hundreds of protozoa into what are termed classes. This is done by taking certain characters that have become specialized, as the presence of cilia in *paramecium*, and the class *Infusoria* is formed. The class *Infusoria* is subdivided on the basis of the permanency of the cilia into two orders: *Ciliata,* which are *Infusoria* that are provided with cilia throughout life, and *Tentaculifera,* which are *Infusoria* that possess cilia in the young condition and tentacles in the adult. The order *Ciliata* may include several species. *A species is usually defined as a number of animals that resemble one another so closely that to know one is to know all.* The several individuals which constitute a species are given a specific name. The scientific names of animals are words which are either Latin or Latinized, or considered and treated as such in case they are not of classic origin. This enables the zoölogists of all nations to speak the same language when referring to animals. There is thus the genus *paramecium* and the species *caudatum,* so that when this particular animal is mentioned it is called *Paramecium caudatum* (page 95).

The plan by which plants and animals are given a definite place in a consistent scheme of classification was worked out by Linnaeus, the great Swedish zoölogist (1707 to 1778, page 23). His plan was to use two words which should show their general relations and individual differences, as already shown for *paramecium,* and for the sake of clearness it may be further illustrated as follows: The cat-like animals were given the generic name of *Felis;* and all that is necessary in naming the several cat-like animals is to add to *Felis* a specific name, as *domesticus* for the common cat or *Felis canadensis* for the Canada lynx. In a similar way the dog-like animals were united under the genus *Canis,* and so there is *Canis lupus,* the wolf; *Canis vulpes,* the fox; or *Canis familiaris,* the common dog.

Every-day observation shows, however, that there is more than one kind of dog, and the species *Canis familiaris* is broken up into varieties. Many difficulties beset the systematist because no two animals are identical, and we have often found even the most important characters of the species modified, so that today one expects a certain range of variation in a species. The result is that species may overlap or pass into one another, and the expert himself is puzzled in classifying some animals.

The multiplicity of species makes it impossible for the average student of zoölogy to understand more than the principles used in classification. The following classification of some of the parasitic protozoa will serve to illustrate how complicated the study becomes and will also serve as a valuable reference to medical students, as several of these protozoa are the cause of certain diseases in man:

- Protozoa
  - Rhizopoda
    - *Amœba*
      - *Amœba dysenteriæ*
      - *Amœba coli*
      - *Amœba meleagridis*
      - *Amœba buccalis*
  - Flagellata
    - *Spirochæta*
      - *Spirochæta obermeieri*
      - *Spirochæta duttoni*
      - *Spirochæta vincenti*
      - *Spirochæta pallidula*
      - *Spirochæta theileri*
      - *Spirochæta gallinarum*
    - *Trypanosoma*
      - *Trypanosoma gambiense*
      - *Trypanosoma cruzi*
      - *Trypanosoma bruzei*
      - *Trypanosoma evansi*
      - *Trypanosoma equinum*
      - *Trypanosoma dimorphon*
      - *Trypanosoma lewisi*
      - *Trypanosoma equiperdum*
    - Trypanoplasma, Cercomonas, Monas, etc.
  - Sporozoa
    - Hæmosporidia
      - Plasmodium
        - *Plasmodium vivax*
        - *Plasmodium malaria*
        - *Plasmodium falciparum*
      - Proteosoma
      - Hæmoproteus
      - Hepatozoön, etc.
  - Infusoria

Intermediate Types.—In all of the study of animals and plants, no one has ever observed one of them coming into being except through the direct influence of a previous living animal or plant. This is now regarded as the biogenetic law (page 114). Whatever may have been the primal origin of life, the present animals and plants are genetically related. This fact makes it necessary to explain the possible origin of organisms consisting of more than one cell or the multicellular forms of life.

This problem is not fully solved, but a fair start has been made through the study of intermediate types.

There are no sharp limits to the several phyla, so that there are a number of animals that fall between certain phyla or are grouped in an appendix to a given phylum. Some of these intermediate forms are interesting because they show how a higher form may have come into existence. This becomes a problem of great interest when the transition between *protozoa* and the next higher form, the many-celled *metazoa,* is made. In the unicellular animals the whole life is carried on within the limits of a single cell. Differentiation of work or structure is lacking, for the whole cell participates in the digestion of food, in metabolism, and reproduction.

The *Colonial vorticellidæ* consist of a number of like individuals arranged in a tree-like fashion (Fig. 77). Each individual is independent in all vegetative and reproductive functions. The cells are similar in size. These animals are termed colonial protozoa, but there is the beginning of cohesion of the cells.

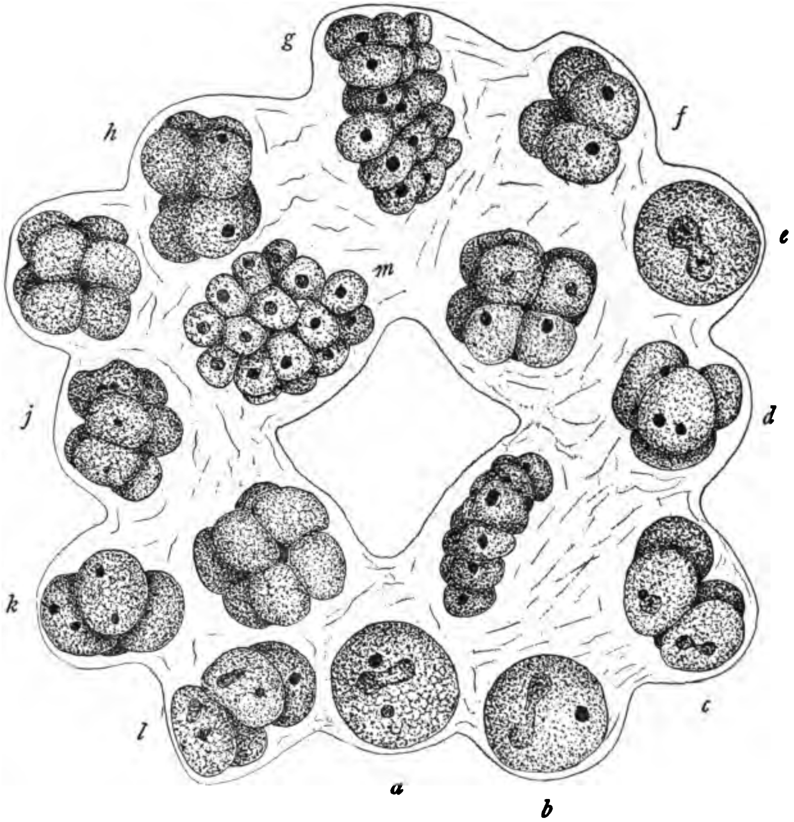


Fig. 117—*Gonium pectorale* in reproduction. Each of the sixteen cells of the colony is dividing to form a daughter colony of sixteen cells. (After Calkins.)

Gonium is a sixteen-cell organism in which the cells are all alike, but united into one common body. Each cell eats, breathes, reproduces, etc. The cells are held together by their own gelatinous secretion. During the reproductive period the cells separate and act like unicellular organisms. This organism shows the first step in the union of cells, although it is not permanent (Fig. 117).

Volvox is an organism consisting of a number of cells varying with the species, from five hundred to fifteen thousand. The cells are arranged in the form of a hollow sphere and are separated from one another by a jelly-like substance through which pass fine protoplasmic threads. The cells are all much alike until the reproductive period, when certain cells become specialized into eggs or sperms. During the growth of these reproductive cells they are nourished by the other cells in volvox. Before one can recognize that there has really been a differentiation of cells the process must have been preceded by the formation of cells of different sizes. This means that unequal cell division is an accompaniment of differ-

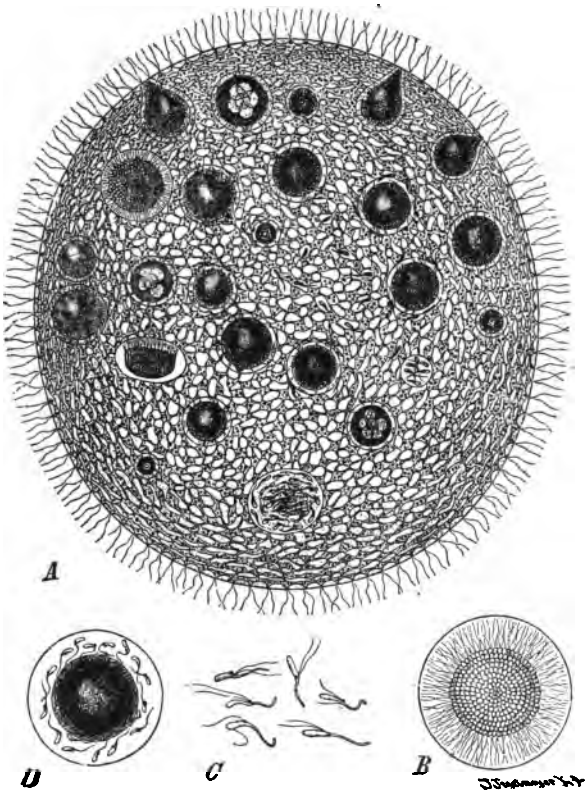


FIG. 118.—*Volvox globator*. *A*, colony containing various stages of development of ova and sperms (× 165). *B*, bundle of sperms formed from division of a single cell (× 530; *C*, sperms (× 530); *D*, egg cell surrounded by sperms in the mucilaginous membrane (× 250). (From F. Cohen.)

entiation. After the cells of volvox have produced and nourished germ cells until they can in turn produce new volvoxes they die.

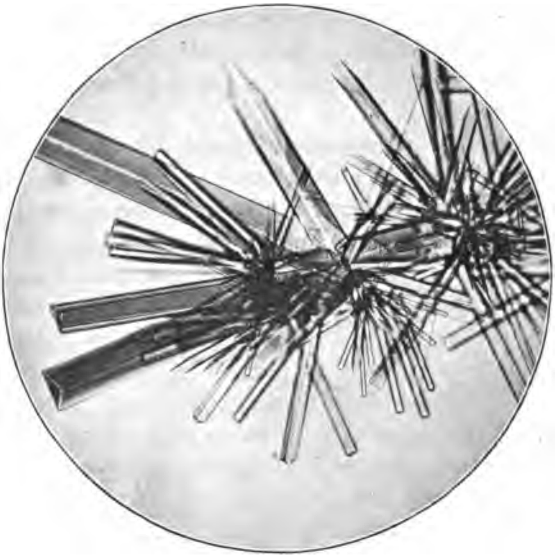


Fig. 119.—Cat.

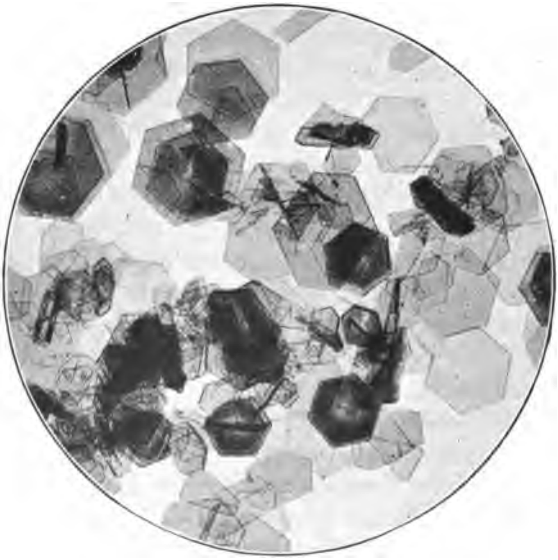


Fig. 120.—Red squirrel.

In these examples given, and many more might be included, there is an obvious transition from the simple to the complex state. The cells tend to become more divergent in structure with an accompanying unification. "For efficient advance in the life scale integration and differentiation must go hand in hand." The higher animals are those in which integration and differentiation have been carried the furthest.

Blood Relationship.—Accompanying the differentiation of animals into many phyla there has undoubtedly been a physiological divergence. Under some conditions this divergence is expressed in definite chemical reactions such as the form of the crystals of the hemoglobin; the crystals of the species of any genus belong to the same crystallographic system, thus affording a critical test of relationship. The difference in the rapidity of the coagulation of the blood shows certain definite peculiarities. It takes from five to eight minutes for the clot to start in the blood of dogs and sheep; twelve to sixteen minutes in the pig; fifteen to eighteen minutes in the horse; and twenty-five to thirty minutes in the bullock. Blood relationship is a phrase used to express the physiologicochemical resemblances that exist among different kinds of animals (Figs. 119 and 120).

CHAPTER XV.

HYDRA—AN ANIMAL MADE UP OF TISSUES ONLY.

Kinds.—There are two common species of hydra that are abundant in fresh-water streams and ponds. Due to the presence of innumerable chloroplastic corpuscles one is bright green, which gives it the name *Hydra viridis*. The other species is of light brown color, due to the presence of yellowish corpuscles, and is known as *Hydra fusca*. *Hydra fusca* is much larger, otherwise the two are very similar. Hydra can easily be seen in an aquarium jar attached to the side nearest the window. They vary in length from 2 to 20 mm.; this is largely due to the fact that the body is capable of great expansion and contraction. The hydra represents a small group of animals in which the absence of well-defined organs made up of tissues such as are found in the frog is a conspicuous characteristic. Nevertheless they are able to do all of the essential things that the frog does to maintain existence. They have been studied for many years as representing the simplest of the many-celled animals.

Morphology.—In general shape the body is a cylindrical sac attached at one end, which is the foot or basal disk (Fig. 121). The foot is not permanently fixed but adheres partly through the action of adhesive gland cells and partly by forming a vacuum. The mouth is somewhat star-shaped and is on the distal end, situated on the top of a conical elevation, the hypostome. Tentacles arise from the body at the junction of the body wall and hypostome and vary in number on *Hydra viridis* from four to twelve and on *Hydra fusca* from six to ten. They are capable of great expansion as they move independently about searching for food and capturing it.

Food.—The hydra is more or less carnivorous, sometimes devouring algæ, etc., but feeding especially on the small water fleas which are seized by the tentacles and drawn into the mouth. The mouth opens and the daphnid is slowly swallowed and passed into the digestive cavity. The indigestible parts are afterward expelled by way of the mouth. Within the body of the hydra there is a single cavity which communicates directly with the hollow tentacles. This cavity serves for digestion and circulatory work, and hence is termed the gastrovascular cavity or enteron.

Structure.—The body of the hydra is composed of two layers of tissue: the outer, the ectoderm, and the inner, the endoderm (Fig. 122). These two layers are separated by a jelly-like, non-cellular layer, the mesoglea, which appears as a line when viewed in a microscopic section. The ectoderm has no connection with the food cavity, so that these cells are nourished only as food is absorbed, first passing through the endoderm and mesoglea. The outer layer of ectoderm serves to protect the hydra and also to act as a generalized sense organ. The protective cells in the ectoderm are the nematocysts

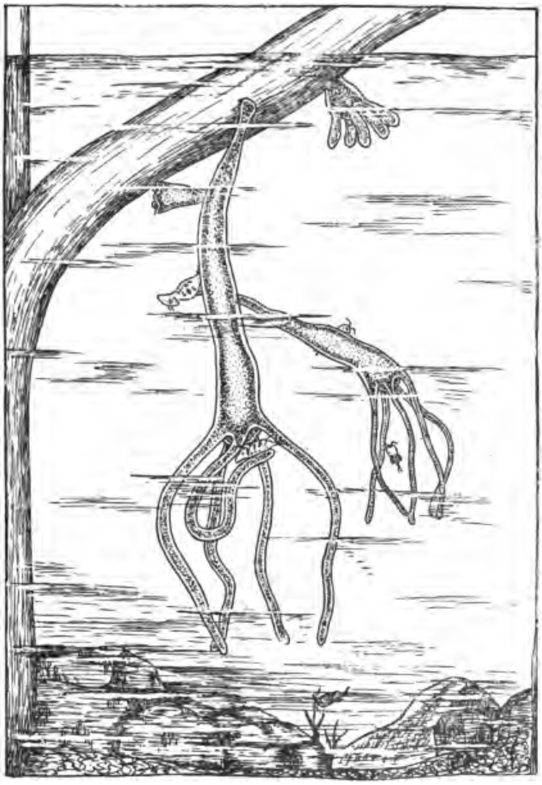


Fig. 121.—The brown hydra of Lake Clear, N. Y. During the summer this hydra becomes a bright red color. It feeds upon daphnia and cyclops as shown in figure. The small specimen attached to the leaf is in the contracted condition. Note the two buds on the body of the large expanded hydra.

which are described below. There are no well-defined sense organs such as ears, eyes, etc., yet the hydra responds to different degrees of light, jars, touch, etc. There are, however, some specialized cells in

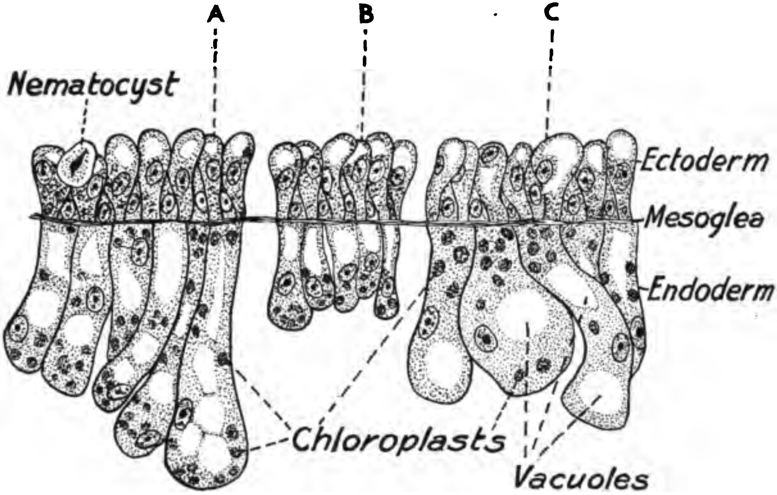


FIG. 122.—Section of the body wall of red-brown hydra taken from Little Lake Clear, February, 1917. *A*, region of esophagus; *B*, middle body region; *C*, taken about one cm. above the region of the foot.

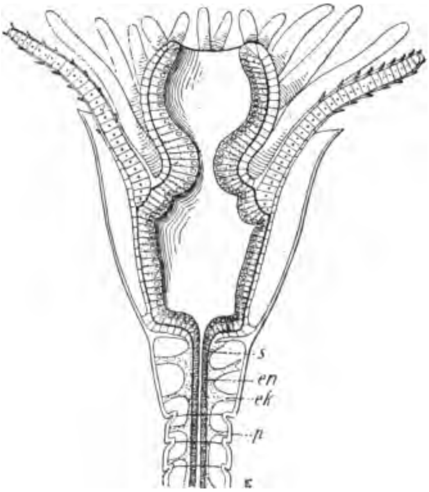


FIG. 123.—Section through the hydranth of *Campanularia geniculata:* *ek*, ectoderm; *en*, endoderm; *s*, mesoglea; *p*, perisarc. (After Hertwig.)

the ectoderm which respond to stimuli and are in connection with an indefinite plexus-like layer of cells to which the name nervous system has recently been given. The endoderm cells are longer than the ectoderm and are of two kinds—glandular and digestive.

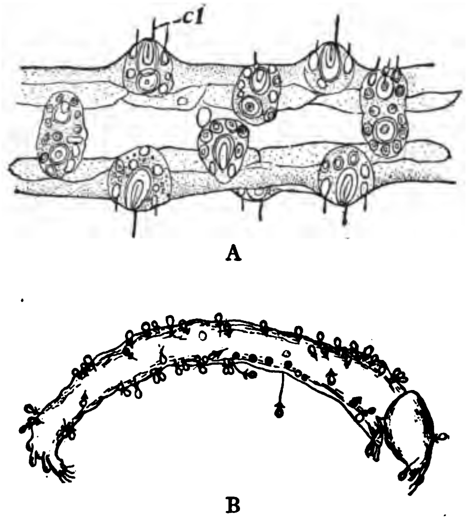


Fig. 124.—Nematocysts and their action: *A*, portion of a tentacle showing the batteries of nematocysts; *cl*, cnidocysts; *B*, insect larva covered with nematocysts as a result of capture by hydra. (From Jennings.)

Nematocysts.—The whole body, and particularly the tentacles, is covered with small projections, from the surface of which are stiff hairs. Each hair is connected with a highly differentiated cell termed the nematocyst or stinging cell. The stiff hair on the surface is called a cnidocil or trigger hair, because when this hair is brought in contact with a water flea, the effect is to cause the nematocyst to discharge a long thread, which penetrates the prey, causing paralysis. The fluid which is contained in the undischarged nematocysts is a poisonous secretion. When a stinging cell has been once discharged, the thread cannot be withdrawn and so is useless to the hydra and a new nematocyst must grow from the underlying cells to take its place (Fig. 124).

Reproduction.—Reproduction in hydra may take place in two ways—the asexual and sexual.

Asexual Method.—The asexual process consists of the formation of a new hydra without fertilization. The usual method is the

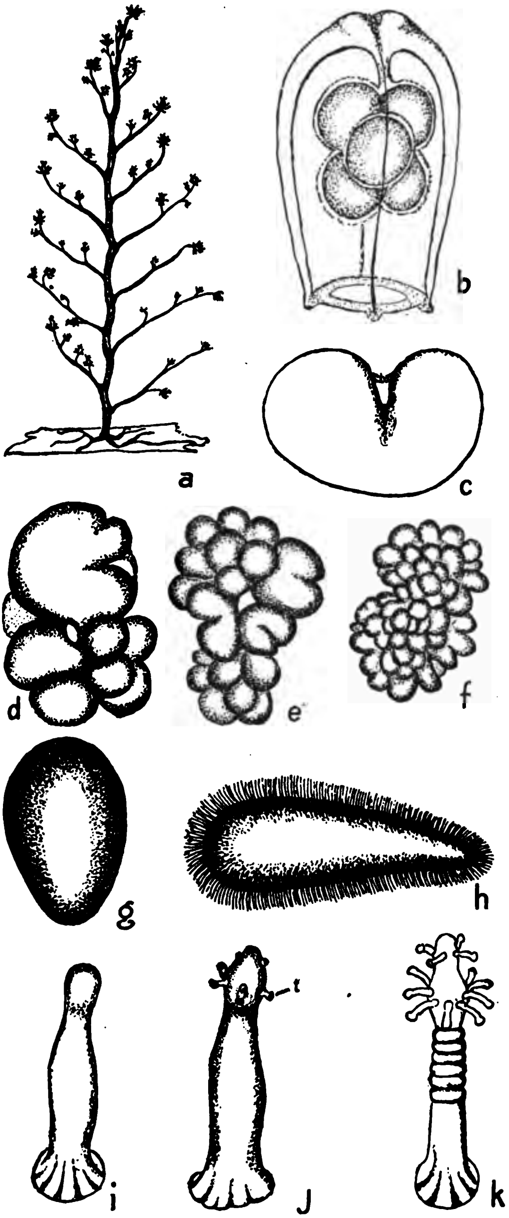


FIG. 125.—*a*, Pennaria tiarella; *b*, medusa with eggs; *c-f*, segmentation stages of embryo; *g-h*, the planula stage; *i-k*, the planula becoming a polyp. The medusa is grown asexually by the hydroid, *a;* while the medusa, *b*, grows either eggs or sperms. The fertilized egg in turn develops into a hydroid instead of a medusa. This method of reproduction is known as the alternation of generations and is illustrated in the stages *a* to *k*. (After C. W. Hargitt.)

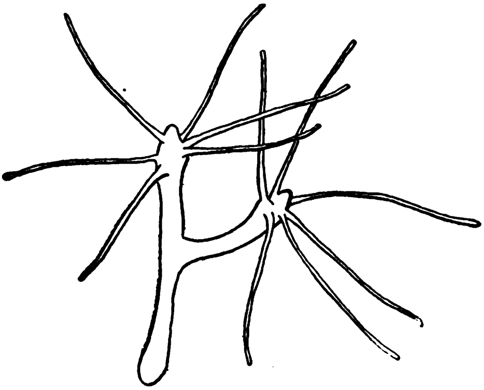


Fig. 126.—Hydra reproducing by longitudinal division. (After Koelitz, in Zoöl. Anz.)

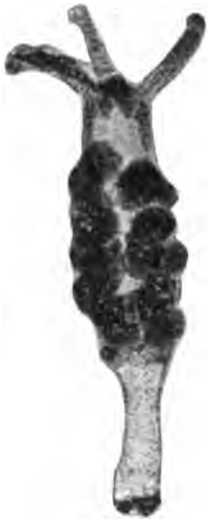


Fig. 127.—Photomicrograph of hydra showing eggs.

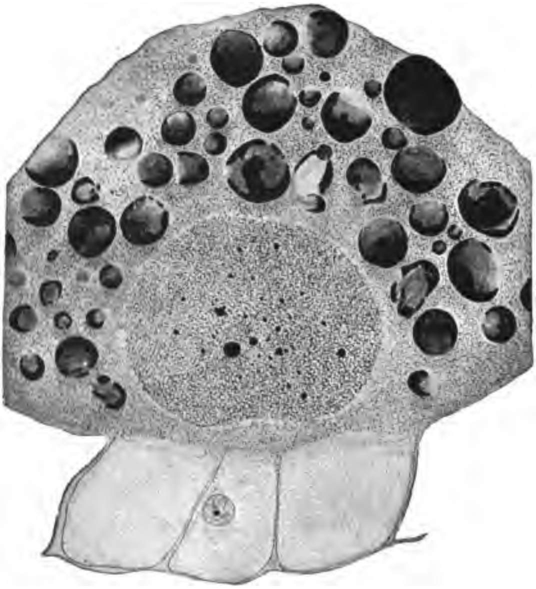


Fig. 128.—The egg of a hydra at about the time that it breaks through the ectoderm and previous to maturation. The nucleus at this time stains lightly, and the pseudo-cells, the remains of the young eggs that have been engulfed by this egg, appear as irregular dark bodies in the cytoplasm. (After Wager.)

growth of one or more buds which first appear as slight bulges in the body wall. These gradually grow in length, small tentacles arise on the free end and a mouth appears. During all this time the gastrovascular cavity of the parent is connected with that in the bud. The rate of growth is largely determined by the amount of food which the parent hydra secures. After a time the bud becomes detached from the parent and leads an independent existence, it is like the parent in all particulars except size and possibly in the number of tentacles. There is also evidence to show that hydra may divide longitudinally as shown in Fig. 129.

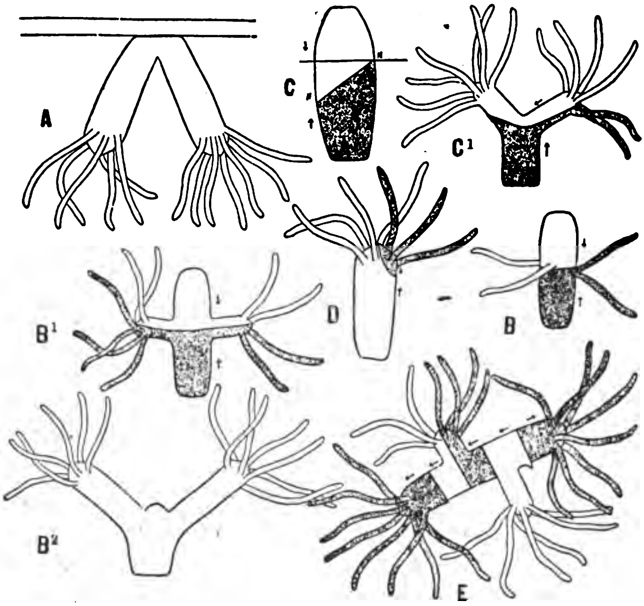


FIG. 129.—*A*, hydra split in two, hanging vertically downward; later, the halves separated completely; *B*, two posterior ends united by oral surfaces; B^1, same, it regenerated two heads, each composed of parts of both pieces; B^2, absorption of one piece leading to a later separation of halves; *C*, two posterior ends united by oblique surfaces; later, one piece partially cut off, as indicated by line; C^1, later still, two heads developed; *D*, similar experiment in which only one head developed; *E*, five pieces united as shown by arrows; four heads regenerated, one being composed of parts of two pieces. (King.)

Sexual Method.—The sexual method of reproduction takes place through the union of sperm and egg cells. The sperm cells are found in small conical, whitish elevations a short distance below the tentacles. When the sperm cells are set free in the water, they continue active for two or three days. The egg begins to grow from one of the small ectoderm cells and gradually increases in size through the engulfing of the surrounding cells. The nuclei of these eaten cells remain for some time in the egg cytoplasm (Fig. 128). Usually but one egg cell reaches maturity. When the egg is mature it undergoes maturation in a manner similar to that described for the frog's ovum, after which the egg is exposed by the breaking down of the outer ectoderm cells. Fertilization takes place as soon as a sperm cell penetrates the cytoplasm, usually within a couple of hours. Segmentation follows in a regular manner until the embryo is hatched. The embryo leaves the parent and remains inactive for some time before it becomes transformed into a hydra. Any animal that bears both sperms and eggs is neither male nor female but both, that is, bisexual. The term hermaphroditism is used to describe this condition.

Regeneration.—Closely associated with the origin of a new hydra, especially by the asexual process, is the power of regrowing parts that have been lost through mutilation. Hydra can be cut into two parts and each part will regrow the part lost. Closely related to regeneration is the ease with which two hydra may be grafted together. This can be done in a variety of ways, often resulting in many-headed forms (Figs. 129 and 130). These cells of the hydra retain the primitive power of growth, although they have taken up definite positions in the organism and their usual work is not that of reproduction. Closely related to this power of regeneration is that of regrowing the entire animal from isolated cells or clusters of cells. In some of the simple sponges and hydroids Osborne has been able to regrow the entire animal from chopped pieces that were strained through cheesecloth (Fig. 131). Such experiments clearly indicate that the body cells have the power to regrow a new individual which is a power that is usually confined to germ cells. These experiments in grafting and regeneration in the hydroids were the beginning of the study of grafting and the study of living isolated cells which, while yet in its infancy as a branch of investigation, has yielded an extensive number of facts that are rapidly becoming of great service to man.

Physiology.—It is interesting to compare the functional activities of hydra with the highly organized frog and the simple paramecium. When the hydra is hungry it goes through characteristic movements even when brought in contact with a piece of filter paper soaked in beef juice. The several movements of the tentacles and the distal part of the body associated in carrying such a piece of filter paper into the mouth are called the food reactions. When a passing cyclops or cypris touches one of the tentacles, it is shot full of nematocysts which paralyze it. The tentacle that is held by its nettling threads to the animal bends and carries to the mouth the food. In this process the other tentacles often assist. As the prey touches the edges of the mouth it is passively swallowed.

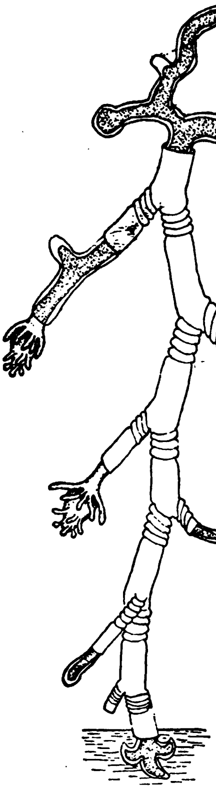


FIG. 130.—*Pennaria* anchored to the bottom of the dish by the distal end, showing regeneration. Unshaded portion is the old stem. (G. T. Hargitt.)

The gland cells in the endoderm now become active and those nearest the mouth pour out a slime which seems to act like the protein-dissolving ferments in the frog. We judge that there are no carbohydrate enzymes present in hydra since starch grains when fed to hydra are ejected unchanged. The action of the slime enzyme is to dissolve part of the food and to break up the rest into minute

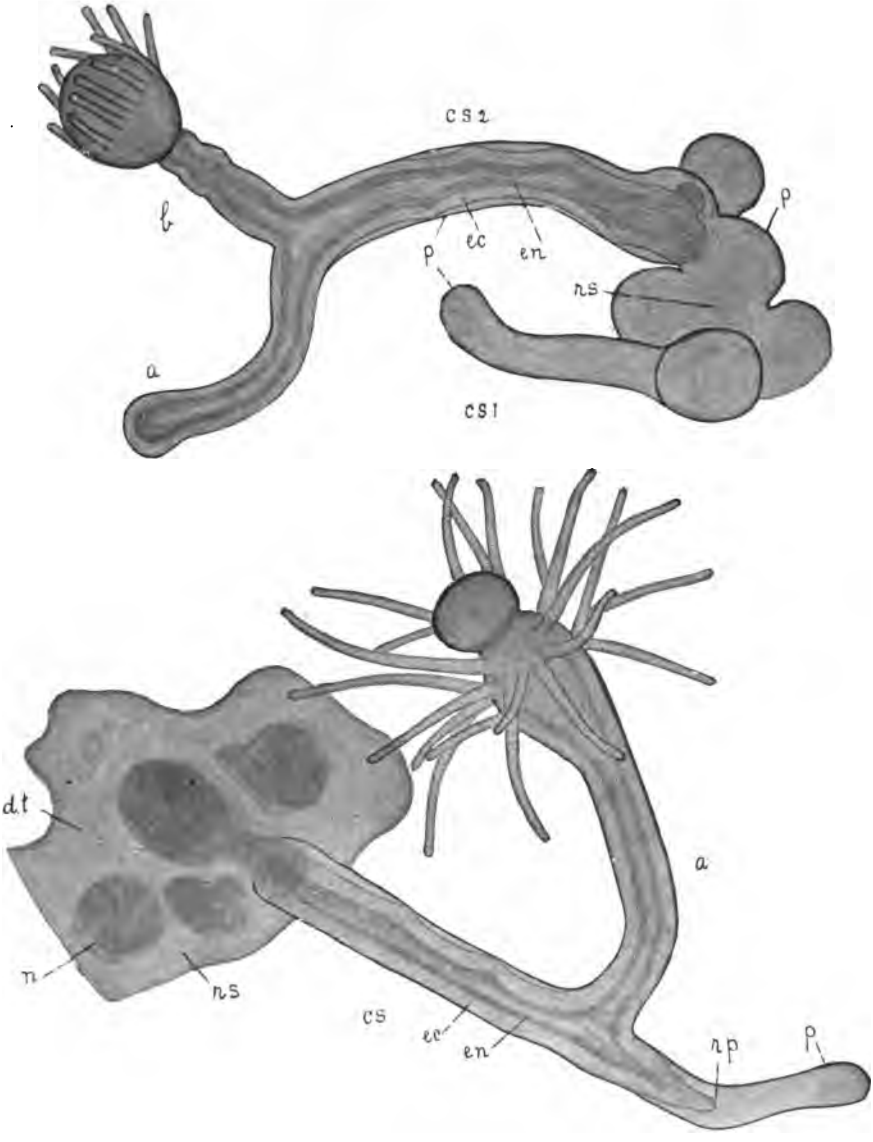


Fig. 131.—After the hydroid has been chopped into small pieces, it is strained through gauze. The hydroid flesh streams through the pores of the gauze and falls into a dish as a fine sediment. This sediment consists of the cells of the body of the hydroid variously dissociated. This figure shows the amount of regeneration that took place in six days in *Eudendrium*. *n*, nodule of living tissue; *ns*, general mass; *cs*, outgrowth which has divided and produced a hydranth on one branch; *ec*, ectoderm; *en*, endoderm; *p*, perisarc of outgrowth; *rp*, regeneration point. (H. V. Wilson, in Jour. of Exper. Zoöl.)

fragments. The dissolved food is absorbed into the cells and is distributed to the various parts of the body. It used to be customary to state that some of the endodermal cells could engulf small particles of food which were digested by the surrounding protoplasm. But the nature of the food, being chiefly minute crustaceans, makes it difficult to see how such a form of digestion could take place. Repeated observations, extending over many years, by Prof. C. W. Hargitt have failed to detect a single instance of the engulfing of particles of food by these endodermal cells. The undigested residue of the hydra's meal is defecated through the mouth.

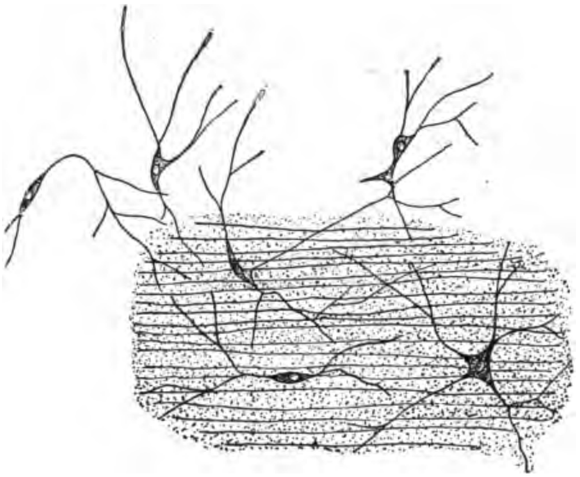


FIG. 132.—Plexus of nerve cells in the ectoderm of *Hydra fusca;* the parallel lines represent the longitudinal muscle fibers on the supporting lamella. (From K. C. Schneider.)

There are no special cells that take charge of respiration and excretion in hydra, but as the whole animal is immersed in the water oxygen is taken in by any of the cells from the water and waste substances are cast off into it. In the frog the skin and lungs absorb oxygen from the air, and the skin at times from the water. The skin and lungs cast off carbon dioxide and the kidneys nitrogenous wastes.

The fact that certain cells are specialized to form even a diffuse network of nerve cells indicates the beginning of differentiation of function. By means of the nerve plexus the tentacles can act in harmony in capturing prey, in moving from place to place, and in responding to various external stimuli (Fig. 132).

The question has often been raised as to the power of an animal like the hydra to initiate movements from within its own body. Jennings has made a special study of this form of movement in hydra and believes that spontaneous movements can be observed. The body and tentacles may contract suddenly and then slowly expand. This is illustrated in Fig. 133.

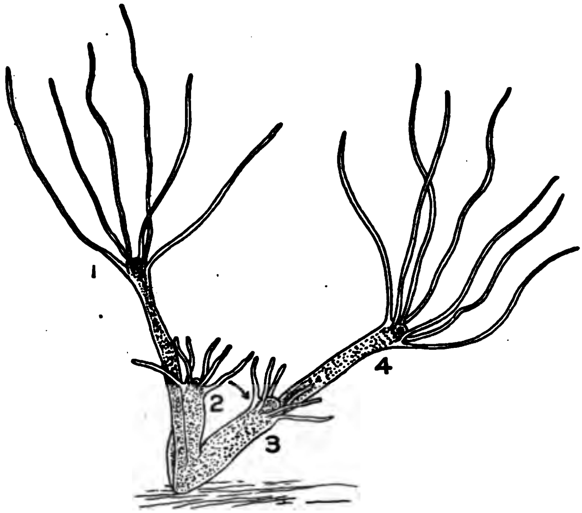


Fig. 133.—Spontaneous changes in an undisturbed hydra. Side view. Extended animal (*1*) contracts (*2*), bends to new position (*3*), and then extends (*4*). (After Jennings, "Behavior of the Lower Organisms," Columbia University Press.)

The hydra exhibits another physiological habit that is not present in the frog. This is the peculiar relation that exists between the hydra and the greenish and yellowish chloroplastic corpuscles. These chloroplastic bodies are minute unicellular plants (Chlorella vulgaris). They are found in large numbers in the bases of the endoderm cells. These bodies are passed on to the offspring through the egg cell or in budding. What is the relation of these cells to the hydra? The hydra is able to carry on all of its life processes with no apparent inconvenience from these cells. Ever since it was shown, by placing a hydra in a weak solution of glycerin, that it could live without these bodies there has been doubt about regarding these plants as beneficial to hydra. The usual explanation has been to regard these very much degenerated plants as using waste carbon dioxide in the manufacture of starch. This waste is given off by hydra. The oxygen set free in the starch-making process is used by the hydra. If the process is mutually beneficial, then we have a condition which is described by the term symbiosis. If the benefits are mostly or wholly one-sided, then the correct term to express the relationship is parasitism.

Winter Life of Hydra.—During the winter of 1916–1917, the writer had an opportunity to study the brown hydra during each month, from November to March. The individual animals came into the State Hatchery at Saranac Inn, N. Y., through the in-take pipe located in Little Clear Pond. These hydra were observed to be in an active state of asexual reproduction during each of these winter months. They were feeding upon minute crustaceans, Cyclops americanus. This study would lead us to believe that these minute and delicate organisms are active throughout the entire year.

CHAPTER XVI.

THE "WORM" GROUP—THE EARTHWORM AS A TYPE.

In all of the older zoölogies there are included under this general term of "Worms" the animals that are arranged in this chapter under phyla IV, V, VI, VII, and IX. There was no real relationship, but the several members looked like worms and were so classed. They all lack well-differentiated body regions, such as a head for example. Some of the parasitic members will be described in the chapter on Parasitism. For the purpose of understanding the plan upon which the body of the worm is organized the common earthworm is the best example.

External Morphology.—The body of the earthworm is long and cylindrical. When crawling it constantly keeps a given surface in contact with the ground; this surface is known as the ventral, and the opposite, the dorsal. The earthworm is said thus to possess dorsoventral differentiation. There is no well-defined head, trunk, or tail. The mouth is located on the anterior end, and internally there are structures which are usually confined to the head region, and so the earthworm is said to have anteroposterior differentiation. The most conspicuous external structural feature of the earthworm is the presence of successive rings varying only in size. These rings are termed somites, and are the external expression of important internal arrangements of the organs. Animals which have somites are said to exhibit metamerism. This tendency to have the same structure repeated must have taken a firm grip on all of the animals that have evolved from the worm stage, as evidence of this plan of structure is continually cropping out. Metamerism is found in all of the arthropods and vertebrates, including man. For this reason alone the earthworm should be studied, as it helps one to understand many otherwise strange structures, such as the segmental arrangement of the muscles in fishes and all vertebrate embryos. The vertebræ, the paired spinal nerves, and intercostal bloodvessels are good examples of metamerism in man.

Habits and Special Senses.—In this connection every student should read Darwin's *Earthworms and Vegetable Mould*. The earthworms are nocturnal in habit and seldom leave their burrows in the ground except during the breeding season. During the daytime they are to be found near the opening of the burrows, but as dry summer comes on they move deeper into it. Earthworms hibernate singly or in numbers below the frost line. They are able to recognize the difference between day and night, although they do not have eyes even in a rudimentary sense. There are a number of specialized nerve cells in the skin that are connected with the nervous system. Structurally these nerve cells are all much alike, yet the worm is able to recognize day and night, certain smells, also jars, and is very sensitive to touch in the head region. The fundamental protoplasmic property of irritability is here concentrated in certain cells in the skin, but these have not become differentiated into the well-known eyes, ears, etc., of the higher animals, and yet the earthworm is able to act as if it had special sense organs. The earthworm has been studied a great deal because of its very simplicity in an attempt to understand just what is essential to a special sense. Here the physiological differentiation has preceded a structural differentiation. A similar case is found in the fact that we can detect the difference between hot, cold, pressure, touch, and pain in our own skin, and neurologists are not able to find definite structural differences between the nerve processes that enable us to recognize these several stimuli. On the other hand, the well-defined eyes and ears enable all of the higher animals to have more accurate information with reference to their surroundings.

Organ Systems.—The organ systems of the earthworm are briefly given because most of the parts are easily worked out in the laboratory. The plan of the body is that of two telescopically disposed tubes, a larger one typifying the body wall, and a smaller one the digestive tube. Between these two tubes there is a considerable space, the coelomic cavity. The cœlomic cavity is partitioned by numerous dissepiments, thin sheets of connective tissue extending from the groove between the somites to the digestive canal. The blood flows through bloodvessels, well defined in the main, and the dorsal vessel acts like a heart in the way that it contracts and expands, thus forcing the blood along. The coelome is also filled with a kind of lymph or blood, which circulates by means of small openings through the dissepiments; it contains numerous white blood corpuscles, which have the power of changing their shape and migrating through the tissues of the body. They are often called leukocytes or phagocytes. The waste leaves the body through the skin and well-defined nephridia located in each somite except the first two or three. The nervous system consists of a ventral nerve chain, with a ganglion for each somite. From each ganglion branches are given off. In the second to fourth somites there are the following changes: the ganglion in the fourth somite is much enlarged, and is called the subesophageal; the two ganglia in the second-third somites are dorsal to the digestive canal, and are called the supra-esophageal ganglia or "brain." The brain ganglia are connected with the subesophageal by commissures.

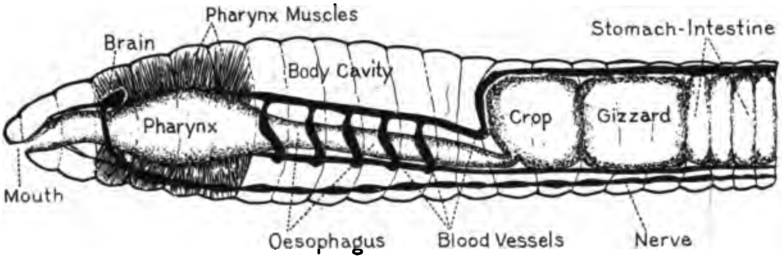


FIG. 134

Reproduction.—The earthworm has both male and female organs of reproduction, and because of this fact is designated an hermaphrodite. The ovaries are paired organs, minute, and pear-shaped, and situated in the thirteenth somite. As the eggs mature they escape from the ovaries and drop into the funnel-shaped openings of the oviducts, which lead to the exterior on the fourteenth somite. The four spermaries are minute flattened bodies in the tenth and eleventh somites. The immature sperm cells leave the spermaries and are retained in three seminal vesicles until mature. The sperms are carried to the outside through a pair of sperm ducts opening on the fifteenth somite. In the ninth and tenth somites there are two pairs of small flask-shaped bodies called seminal receptacles. These bodies have no structural connection with any of the other reproductive organs.

Although the earthworm is hermaphroditic, it is not self-fertilizing, for there must be an exchange of sperms. This is effected in copulation, when the seminal receptacles are filled with sperms from another animal. As the egg-laying period approaches, the clitellum secretes a viscid mucus, which hardens and toughens on exposure to the air, thus forming a membrane. This membranous girdle is pushed forward, receiving eggs from the oviduct and sperm cells from the seminal receptacles. In this way the eggs are fertilized by sperms from another animal. Finally the capsule is pushed from the head end of the worm, each end contracting as it leaves the animal to form a cocoon. In this cocoon the embryos grow, feeding on the enclosed food and devouring each other until but one usually reaches maturity.

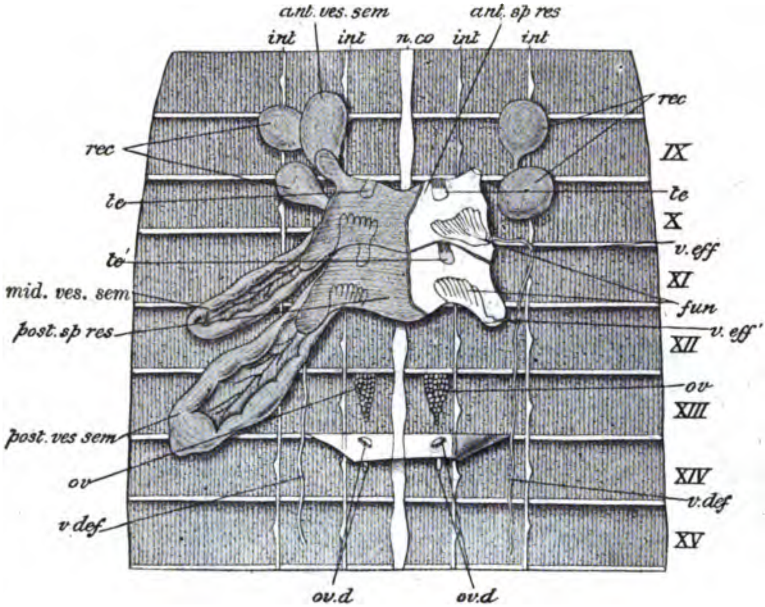


FIG. 135.—*Lumbricus agricola.* Reproductive organs; *ant. sp. res*, anterior sperm reservoir; *ant. ves. sem*, anterior left vesicula seminalis; *fun*, funnel-like openings of vasa efferentia; *int*, intermuscular partitions; *mid. ves. sem*, middle vesicula seminalis; *n. co*, nerve cord; *ov*, ovaries; *ov.d*, oviducts; *post. sp. res*, posterior sperm reservoir; *post. ves. sem*, posterior vesicula seminalis; *rec.*, receptacula seminis; *te'*, anterior testes; *te*, posterior testes; *v. def*, vasa deferentia; *v. eff.*, vasa efferentia. (After Vogt and Jung.)

During the formation of the embryo from the fertilized ovum the changes are regular and follow a distinct plan. After segmentation has taken place for a time the mass of cells takes up a regular arrangement so that definite terms are used to describe the conditions. The cells on the outside are the ectoderm cells and those within, the endoderm. After further growth a middle layer (mesoderm) is recognized and the embryo is said to have three germ layers. From each of these germ layers distinct parts of the body arise, to illustrate:

Ectoderm {
- Nervous system.
- Part of nephridia.
- Epidermis.
- Lining of mouth and vent.

Regeneration.—The earthworm is an interesting animal in which to study this power to regrow lost parts; for if any of the first seven or eight somites are removed, all will be regrown, but when more are cut off only this definite number form again. Thus if the first fifteen somites are removed, seven or eight will grow and the intervening ones will always be lacking, thus rendering the animal sterile. When somites are removed from the posterior end the regenerated part is at first composed of a very few somites. The terminal somite contains the new anal opening, and new segments are formed just in front of this terminal somite, the youngest being the one next to the end. This method of adding somites continues until all of those removed have been replaced. The worm cannot be split lengthwise and live. Hydra may also be studied to advantage in connection with this power of regeneration; or if hydra are not available, the flatworm, planaria, is excellent.

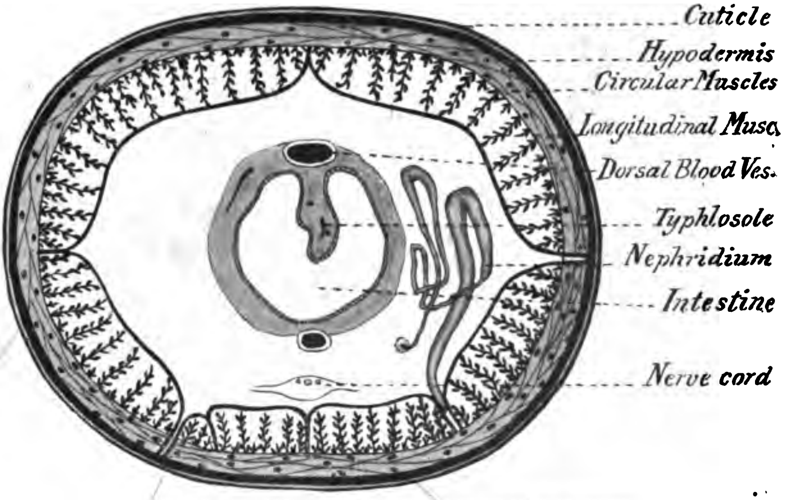


FIG. 136.—Diagrammatic cross-section of earthworm.

Histology.—In the histological analysis of the frog definite tissues were discovered as the several organs were studied. In a similar study of the earthworm definite tissues are found, each having its own position in the body (Fig. 136).

The following tissues are found in the earthworm: columnar, ciliated, and pavement epithelium, muscular, nervous, and blood, which can be easily studied. It is not easy to differentiate the connective tissue. In a diagrammatic cross-section, the arrangement of these tissues is indicated. The body of the earthworm is covered with a secretion that hardens into a tough membrane, the cuticle. There are no cells in the cuticle, so that it cannot be termed a tissue. Immediately under the cuticle is a modified columnar epithelium containing special slime cells and sense cells in addition to the regular columnar cells. Next follows a circular and longitudinal layer of muscle. In the first the cells are cut lengthwise; while in the second they are cut crosswise. The inner end of the longitudinal muscle layer is limited by the pavement epithelium which appears in section as a line. These several layers constitute the body wall. On the ventral surface the body wall is indented to allow the setæ to pass out. In the center of the section is the digestive canal which is best studied back of the clitellum. A large bloodvessel marks the dorsal region while a small one, often detached in cutting, is on the ventral

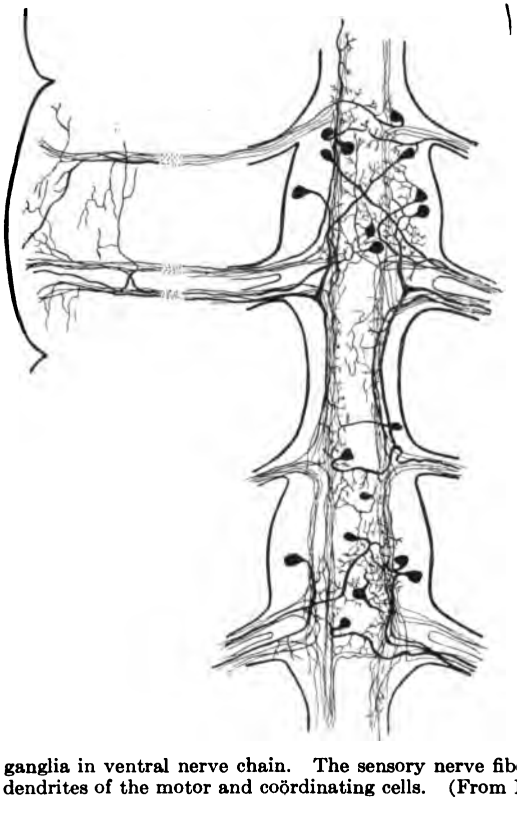


Fig. 137.—Two ganglia in ventral nerve chain. The sensory nerve fibers of the skin end in the dendrites of the motor and coördinating cells. (From Retzius.)

side. The intestine is usually folded in this region, the fold bending in from the dorsal surface. This fold is termed the typhlosole. The wall of the intestine is composed of a glandular epithelium on the outside and a columnar and cilated epithelium on the inside. Between these two layers a few scattering muscle cells and blood-vessels are found.

On the ventral surface of the body wall is found the section of the nerve cord. This is a double cord which gives off nerves in each somite. Special stains are necessary to make out the details which are shown in Fig. 137. There are definite cells that send their processes out to the skin, where they receive the stimuli that have been transmitted by the peripheral skin sense cells. Other nerve cells send their processes to the muscles. A very few nerve cells do not leave the nerve cord but connect the adjacent ganglia with each other. These are the associational fibers. The same terms of afferent and efferent that were used in describing the frog's nerves can be applied here. The earthworm shows a marked advance over the hydra in that the nerve cells are collected into a definite organ and in that definite work is assigned to given neurons. The several ganglia are in communication with each other, but in a poor and incomplete fashion as compared with the frog. In this sense the earthworm stands as an illustration of the beginning of the development of the associational fibers which later become so important in the development of the nervous system.

CHAPTER XVII.

MOLLUSCA.

General Characters.—The mollusca are known to have existed since the early Palæozoic epoch. The mere fact that this phylum was clearly defined at such an early date probably means that their origin and relation to the other invertebrate phyla is lost forever. In this phylum there are more than 60,000 living species.

The name mollusca means soft-bodied animals, usually with an external shell; they are also characterized by a general absence of metamerism; and by the coelome being reduced to inconspicuous remnants around the heart and to the lumen of the gonads. The presence of a mantle which secretes the shell, a wide variety of relations between the foot and head (a head being absent in clams), and sexual reproduction constitute the characteristics which distinguish the clams, oysters, snails, octopi, etc., from all other animals.

The fact that clams and oysters are so generally used as food and so frequently cause disease is alone warrant for studying this aberrant group in a general course in biology. In this account only such structures are described as are necessary in understanding their method of feeding.

The calcareous shell of the clam consists of a right and left valve held together by a hinge ligament. The valves are held in contact by adductor muscles, one anterior and one posterior. When these muscles relax, the elasticity of the hinge ligament opens the shell. The shell grows in a regular manner so that one can easily tell which region is older. The oldest part of the shell is the small, conical knob, the umbone, just anterior to the hinge ligament. There are many concentric lines of growth on the surface of the shell, each of which marks a brief resting period. The youngest part of the shell is the outer margin. The ordinary clam on the market is from three to five years old, although there are 50 or more lines of growth.

When one valve is removed after cutting the adductor muscles, the inside of the shell appears as noticeably smooth and of a pearly luster. Muscle scars indicate where the muscles were attached. Along the hinge ligament margin various forms of interlocking teeth are found which keep the shell from slipping.

As one examines the soft body of the clam he finds the whole visceral mass covered by a thin membrane, the mantle. The mantle is a structure peculiar to the molluscs. It has two general uses: (1) it secretes the shell; (2) it is the main organ of respiration. The two

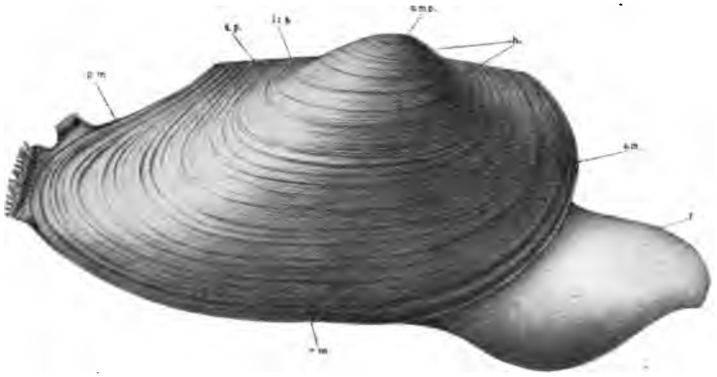


FIG. 138.—***Anodonta fluviatilis.*** ***a.m.***, anterior margin; ***p.m.***, posterior margin; ***d.p.***, dorsal margin; ***v.m.***, ventral margin; ***lig.***, hinge ligament; ***f.***, foot extended; ***umb.***, umbo; ***h.***, hinge-line. Notice the position of the two siphons and the shape and size of the foot. (After Simpson.)

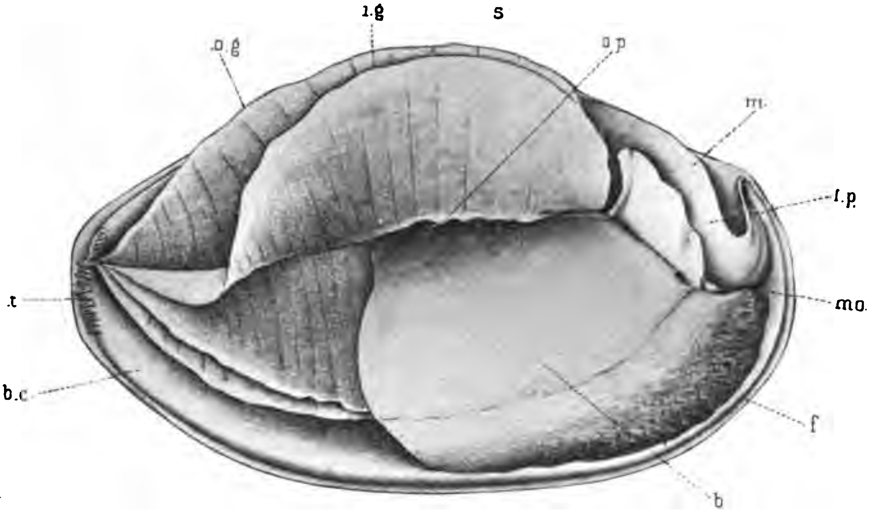


FIG. 139.—***Anodonta fluviatilis***, showing the mantle and gills thrown back, exposing the foot, body and labial palps. *f.*, foot; *b.*, body; *i.g.*, inner gill; *o.g.*, outer gill; *b.c.*, branchial cavity; *l.p.*, labial palpi; *m.*, mantle; *mo.*, mouth; *op.*, opening through the gills for the passage of the body; *t.*, tentacles of inhalent siphon. (After Simpson.)

folds of the mantle completely line the shell. On the posterior margin the mantle frequently becomes specialized into two tubes, the dorsal one serving for the escape of wastes while the ventral is the inlet into the mantle cavity for sea-water containing food. These two openings are the excurrent and incurrent siphons (Figs. 138 and 139).

The visceral mass of the clam consists of a large ventral muscular foot which merges dorsally into the several organ systems (Fig. 140). On each side of the visceral mass two pairs of gills are attached, their free edges hanging down in the mantle cavity.

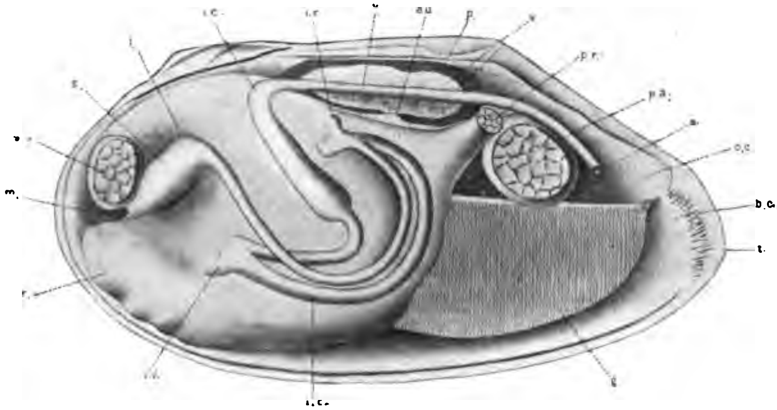


FIG. 140.—*Anodonta fluviatilis* dissected to show intestinal canal. *a.a.*, anterior adductor muscle; *au.*, auricle; *a.*, anus; *b.c.*, branchial chamber; *c.c.*, cloacal chamber *f.*, foot; *g.*, gill; *i.c.*, intestinal canal; *l.*, liver; *m.*, mouth; *p.*, pericardium; *p.a.*, posterior adductor muscle; *p.r.*, posterior retractor muscle; *s.*, stomach; *v.*, ventricle. (After Simpson.)

Food of Clams and Oysters.—Clams and oysters are passive feeders and possess no organs for seizing food. The cilia on the gills cause a current of water to be drawn in through the incurrent siphon. The water strains into the interior of the gills and finally passes out through the excurrent siphon. As the water in the mantle cavity comes in contact with the mucous secretion on the surface of the gills, all solid particles are caught. This mucous secretion is moved by cilia on the gills toward the mouth. On each side of the mouth there is a pair of labial palps (Fig. 139), which are covered with cilia, and these assist the gill-cilia in moving and directing the food-laden mucus into the mouth. The entire digestive tube is lined with cilia which are probably solely responsible for keeping the food and mucus moving in the digestive canal.

The food of clams and oysters consists mostly of minute plants, diatoms usually predominating. Some authorities state that unicellular algæ, protozoa, eggs, and various minute larvæ are eaten. The natural food of the edible clams and oysters lives in brackish water, especially at the mouths of rivers emptying into the sea. Long Island Sound and Chesapeake Bay are two such notable places.

The diseases caused by eating raw shell-fish are due to the following causes: Clams and oysters do not feed upon B. coli and B. typhus, for example, nor do these organisms live as parasites on the clam or oyster. In fact, these bacteria are not even adapted to life in the clam and oyster, for oysters when innoculated with B. coli and isolated do not give cultures of the inoculated bacteria after two weeks when kept at room temperature. This would seem to indicate that the disease-causing organisms were carried into the mantle cavity where they are left by the water and here they remain until they die. Oysters and clams must become reinfected at frequent intervals to be continuously dangerous as food. The relationship which B. coli, and B. typhus have to the clam and oyster is a purely mechanical one. Clams and oysters will purify themselves in the course of two days if transferred to pure sea water.

CHAPTER XVIII.

THE CRAYFISH.

Kinds and Distribution.—Crayfish have been known to scientists ever since Aristotle wrote about the "Small Astaci Which Breed in Rivers." In the United States there are some 70 species of crayfish, the most of which belong to the genus Cambarus, there being but 5 species of the genus Astacus.

Faxon says these two genera occupy distinct geographical areas. The genus Astacus is found in the old world in Europe and Western Asia as far as the Aral and Caspian seas, and in America in the region west of the Rocky Mountains in the streams draining into Great Salt Lake and the Pacific Ocean. It is thus seen to occupy the western sides of two continents. Cambarus is found in North America east of the Rocky Mountains in the region which is bounded on the north by Lake Winnipeg and New Brunswick, and on the south by Guatemala and Cuba.

The crayfish are commonly found in streams and ponds, although one species lives in moist meadows in burrows. Economically the Astaci are valued as food by foreigners, and crayfish farms are maintained to supply this table delicacy. In the cotton belt, crayfish kill the young cotton plants by eating the tender roots.

Food.—While crayfish act as scavengers, eating various kinds of dead animals, they seem to prefer living animals, such as tadpoles small frogs, insect larvæ, etc. They also prey upon each other. During the daytime crayfish are inactive, but begin feeding at dusk and continue during the night.

General Characteristics.—Among the invertebrates the hydra, earthworm, and crayfish are the animals best known to biological students. The reason for this nearly universal familiarity is that each exhibits important fundamental steps in the evolution of animals. The crayfish, in addition, is studied as a type of the most numerous phyla of the invertebrates, the Arthropoda; for here are classed according to some authorities more than six hundred thousand different species, all of which have three structural characteristics in common. These are the presence of modified somites, an exoskeleton and jointed appendages.

Modified Somites.—The body of the crayfish is divided into the anterior immovable region, the cephalothorax; and the posterior movable, the abdominal. The somites in the abdomen are all similar excepting the first and last. Each typical somite supports a pair of appendages. It is easy to recognize in the somites of the abdomen the simpler plan that exists in the earthworm. The question naturally arises as to how many somites have united to form the cephalothorax. Inasmuch as a typical somite supports a single pair of appendages, by counting the number of pairs of appendages in this region the problem is solved. Such an enumeration reveals that there are thirteen pairs, not counting the eye-stalk. This means that thirteen somites have united to form this cephalothorax region.

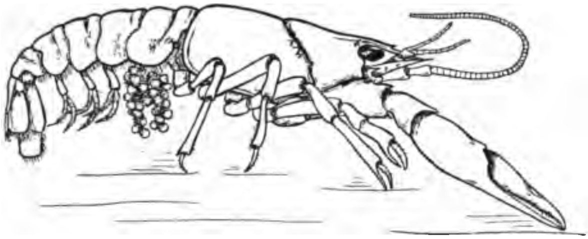


FIG. 141.—Crayfish bearing eggs.

In reaching this important conclusion one must have recourse to the facts of embryology which reveal the primitive and successive changes through which this region has passed. The cephalothorax of the crayfish not only shows how a general body region may have arisen as a modification of somites, but also how the head and thorax as distinct regions may have become differentiated, for there is a distinct groove in the carapace, the exoskeleton of this region, which marks off the head region from the thorax.

Exoskeleton.—The surface of the body is covered with a chitinous cuticle made hard by impregnated lime salts. This peculiar substance is composed of the following chemicals probably having this arrangement: $C_8H_{15}NO_6$. Wherever there is a joint this exoskeleton is thin and flexible, thus allowing movement. Such an external skeleton naturally limits the growth of the crayfish and prevents an increase in size. Yet common observation proves that young crayfish do grow larger. To allow this increase in size the whole of the exoskeleton is shed and the process is known as moulting or ecdysis. In moulting the old skeleton loosens and drops off while the underlying cells secrete a new covering of chitin. Moulting also takes place in adult crayfish and the process necessitates that the lime be absorbed along the dorsal line of the head-thorax region and that the joints soften. The exoskeleton then splits along the line where the lime has been absorbed, the blood is withdrawn from the limbs and the whole anterior part of the body withdraws from the old shell. The abdominal region is drawn out last. The lining of the esophagus, the stomach and the hind intestine is also removed because they arise through an infolding of the skin. While some of these details do not apply to all Arthropoda, the main facts do.

Jointed Feet.—The scientific term, Arthropoda, describes this easily recognized characteristic. All members of this phylum have more than two pairs of jointed appendages, which in general move by hinge-joints. The appendages of the crayfish also furnish an interesting study in adaptation, as all of them can be shown to have the same general parts at first (Fig. 142).

Apparently the primitive form of appendage is the one found on most of the abdominal segments, called the swimmerets. Such an appendage (Fig. 142) consists of a simple basal protopodite supporting two flattened branches, the outer, an exopodite, an inner the endopodite. The last abdominal pair of appendages is enlarged, although no new structures are added. The same three primitive parts are readily distinguished (see uropod in Fig. 142). In a similar manner the several walking appendages are compared with the typical or primitive abdominal. In these there has occurred the loss of the exopodite, and the distinct jointing of the endopodite. Sometimes the terminal joints are opposite and form pincers (Fig. 142). Anterior to the walking appendages occur six pairs that assist the crayfish in securing, tearing and crushing its food. Fig. 142 shows the form and parts of one of the three maxillipeds and the mandible. In a similar way the two antennæ are compared with the same typical abdominal appendage. Each of the antennæ has the endopodite greatly enlarged and double in the smaller one (Fig. 143). The only evidence of the exopodite in these two appendages is the large scale at the base of the large antennæ. It is expected that this general description of the similarities between the appendages will be supplemented by a detailed laboratory study.

A full comparison of the appendages of the crayfish necessitates a thorough knowledge of their embryology. In this way one determines which parts have been lost and which retained. Fig. 143 shows the walking appendages of the lobster with both an endopodite and exopodite. A similar stage in the development of the crayfish shows the same parts. While in the adult crayfish the several appendages have become adapted to swimming, walking, food-getting, feeling and tasting; yet a study of their development clearly indicates that each one is derived from the primitive abdominal type.

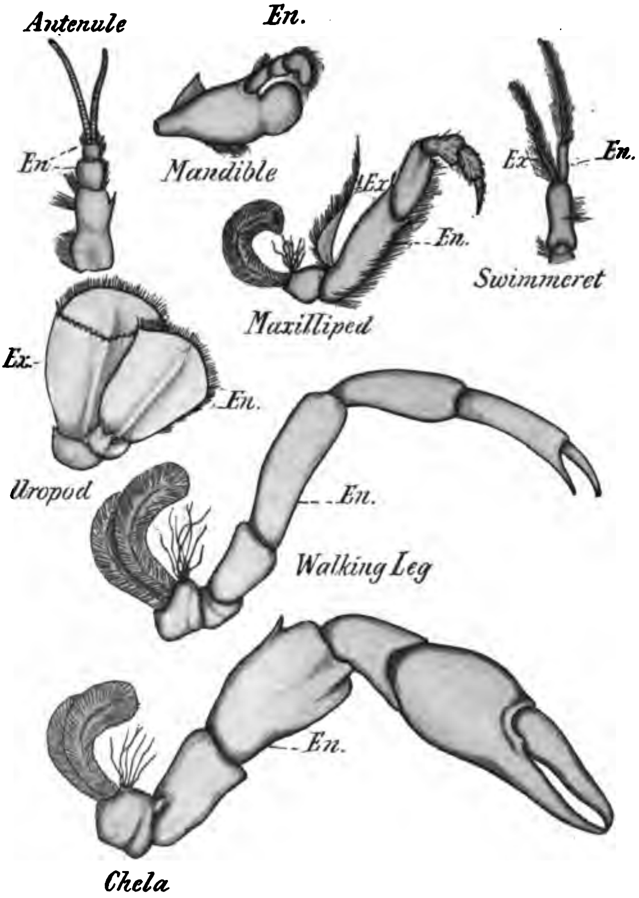


FIG. 142.—Appendages of crayfish.

In this comparison of the appendages of the crayfish in which highly specialized feet are shown to have parts in common with all the rest, an important method of explaining many of the specializations in plants and animals is illustrated. Such structures as the appendages of the crayfish are termed *homologous organs* because they have had a common embryonic origin. The fact that in the adult stage these organs are widely divergent in appearance and use does not interfere with the more fundamental fact of a common embryonic origin. (For a further discussion see Homology, p. 245).

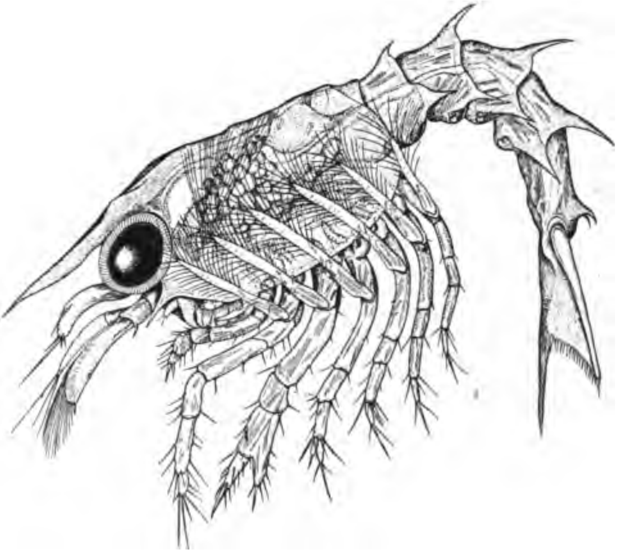


FIG. 143.—First larval stage of lobster, showing the biramus appendage in the thoracic region. The embryonic exopodite disappears.

Organ Systems.—The several organ systems of the crayfish are all clearly defined, and in the nervous, reproductive and excretory systems are of a higher order than in the earthworm (Fig. 134).

The mouth is ventral in position and bounded by modified appendages. It opens into a short esophagus that expands into a capacious stomach. The stomach is divided into two regions by a constriction. The anterior is the larger and known as the cardiac stomach, while the small or posterior is the pyloric. A straight intestine extends from the pylorus to the anus located on the last abdominal somite and opening ventrally. In the cardiac stomach the chitinous lining is thickened in certain parts to form ossicles. These are arranged in such manner that the food is chewed by them. The several ossicles constitute the gastric mill.

On each side of the stomach is located a pair of digestive glands sometimes called the liver. Each gland consists of three lobes. The glandular epithelium lining the numerous tubules in each gland secretes a digestive fluid that is very complex. The food of the crayfish consists of proteins, carbohydrates and fats, consequently it is not correct to designate this gland as a liver but rather as a pancreas. The digestive enzymes of this gland are probably the following: (1) a protease enzyme which acts upon the proteins: (2) a lipase, the fat-emulsifying enzyme; (3) cytase, a cellulose-dissolving enzyme.

The crayfish breathes by means of gills contained in a narrow chamber protected by the overhanging carapace. The two rows of gills are named from their attachment as podobranchs when fastened to the protopodites and constitute the outer row. The second row is made up of the arthrobranchs as they are attached to the articular chitin at the base of the appendages.

Each gill consists of numerous small filaments arising from a central axis. Two bloodvessels penetrate the base of each gill and give off a branch to each filament. The blood courses in through one and out through the other during which process oxygen is taken from the water and waste carbon dioxide given off. The gill is an out-pushing of the body wall which is shown by the fact that it contains the same layers as the body wall.

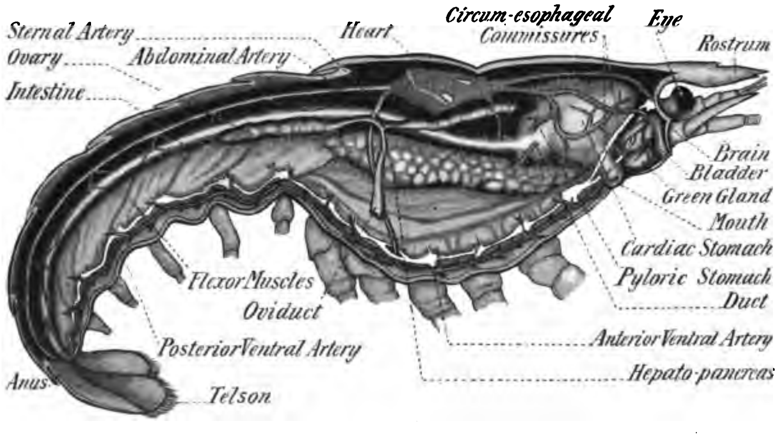


FIG. 144.—Median section of crayfish.

The nephridia of each somite in the earthworm are limited to a single pair, the green glands, located in the anterior ventral part of the head. Each gland is divided into a glandular portion and a thin-walled bladder. The execretory duct opens on the ventral surface of the basal segment of the large antenna (Fig. 144).

The colorless blood-containing ameba-like blood corpuscles carry on the usual functions of the blood. There are well-defined arteries and a definite heart that beats rhythmically. Valves in each artery as they leave the heart prevent the blood from flowing back into the heart. After the blood is carried to the tissues it passes into irregular spaces termed sinuses. From the sinuses it is carried to the gills and from the gills to the pericardial sinus. The heart has several openings, the ostia, through which the blood enters the heart and is prevented by valves from escaping.

The muscles which enable the many joints in the appendages to bend in so many directions are numerous and arranged in pairs. Large muscles to flex the abdomen in swimming occupy nearly all of the space in the abdomen. These muscles are the chief source of food for man.

The crayfish, unlike the earthworm, normally contains the reproductive organs of but one sex. There is a single testis located beneath the pericardial sinus. It consists of two lobes on the anterior end and a single medial lobe posteriorly. From each side a coiled vas deferens passes to the protopodite of the fifth pair of walking appendages. The ovary is located similarly in the female and has a short, straight oviduct that opens in the protopodite of the third walking appendage. When crayfish copulate, the males deposit sperms in a cavity on the ventral surface of the cephalothorax called the seminal receptacle. Here they are stored from October until egg-laying in the spring. Previous to egg-laying the female cleans the ventral surface of the abdomen and a slime is secreted by cement glands located in the abdominal appendages. This slime is spread over the swimmerets. The female then lies on her back and the one to six hundred eggs become attached to the hairs. Just how the sperms are distributed to the eggs is not known. The female keeps the eggs aërated and free from dirt. The eggs hatch in from five to eight weeks (Fig. 141).

The position and general morphology of the nervous system reminds one of the simple series of nerve ganglia in the earthworm. The series of ganglia in the abdomen are found in the six somites, regularly distributed. But this simple arrangement is not found in the cephalothorax for the primitive somitic simplicity is lost in the fusion of two or more ganglia into single large nervous masses. This is particularly evident in the ganglia beneath and above the esophagus. Five thoracic ganglia can be recognized, but there are thirteen somites in the cephalothorax, so that the natural inference is that the brain and subesophageal ganglia together represent these eight remaining primitive ganglia. This is on the assumption that each somite originally contained a single ganglion, for which there is a good deal of embryonic evidence. From each ganglion several pairs

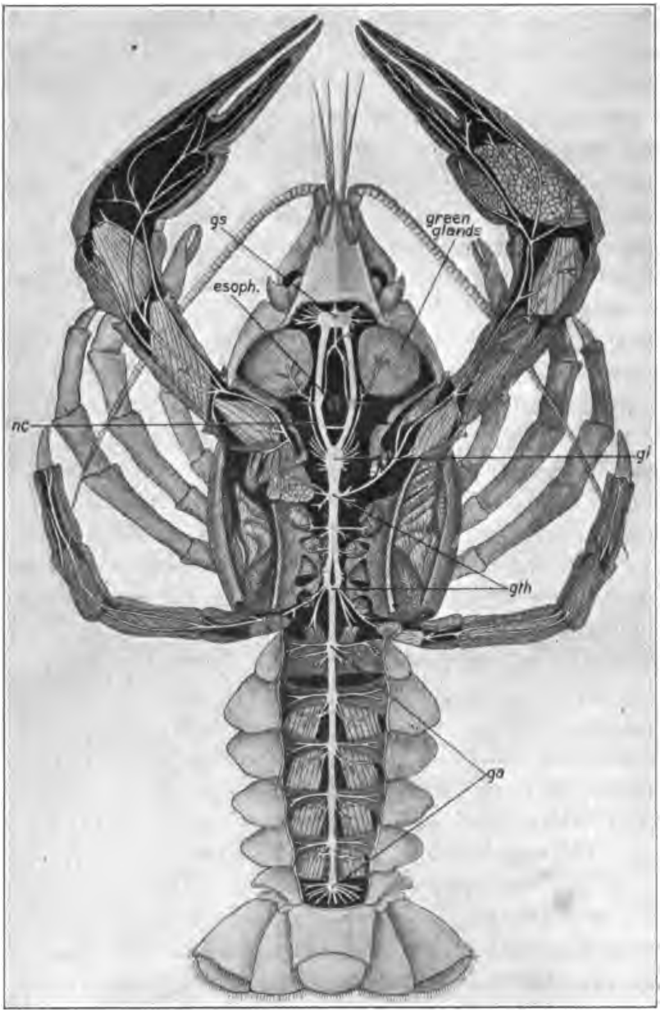


FIG. 145.—Nervous system of European crayfish. *esoph.*, esophagus; *ga*, abdominal ganglia; *gi*, infra-esophageal ganglion; *gs*, supra-esophageal ganglion; *gth*, thoracic ganglia; *nc*, nerve collar. (After Wilhelm Klein.)

of nerves pass off, and from the brain and subesophageal many branches. The eye, the antennæ, and even the stomach receive nerves from the brain. The internal structure of the ganglia of the crayfish shows many more association nerve cells than are present in the earthworm which is the real test as to which is the higher.

The crayfish shows a marked advance over the earthworm in the development of sense organs. Sense organs of touch, smell, taste, equilibrium, and vision are all present. The entire body is sensitive to touch, especially the mouth parts and ventral surface of the abdomen. This sense is located in specialized hairs. Smell and taste are so closely allied that it is proper to designate them by the single term chemical sense. When meat juices are applied to the various parts of the body definite responses are made and in some instances a series of movements follows which are well described as the feeding reflexes. The chemical sense is better developed in the mouth appendages than anywhere else. In the base of each small antenna is an open sac containing over 200 hairs. Each hair is supplied with a nerve. Small bits of sand are found in the sac. The whole structure was early called an auditory organ. Recent studies have failed to prove that the crayfish hears. When the ear sacs are removed or the ear nerves cut the crayfish swims in nearly any position, apparently just as well upside down as right side up. This suggests that these organs are for balancing or informing the crayfish when it is in its normal upright position. This is not an exclusive sense function of the crayfish but is present in some jelly-fish, snails and vertebrates.

The eye of the crayfish is on the end of a movable stalk. It is described as a compound eye because there are about 2500 distinct visual elements united in each eye. The external skeleton of chitin is transparent over the end of the eye-stalk and for this reason is called the cornea. Fine lines divide the cornea into four-sided areas, called facets. Each facet corresponds to the individual visual element known as an omatidium. The compound eye produces an erect mosaic, as all of the rays of light that impinge on the pigment in each omatidium are absorbed. The only rays that are able to reach the sensitive part are those that pass directly through the center of the cornea because such rays reach the optic nerve. Each omatidium gives an incomplete picture of an object, but when the many partial pictures are united the whole object must appear as a mosaic. Such eyes are well adapted to detect movement in an object, as any change in position of a large object would be recorded in most of the 2500 omatidia.

REFERENCES TO CRAYFISH.

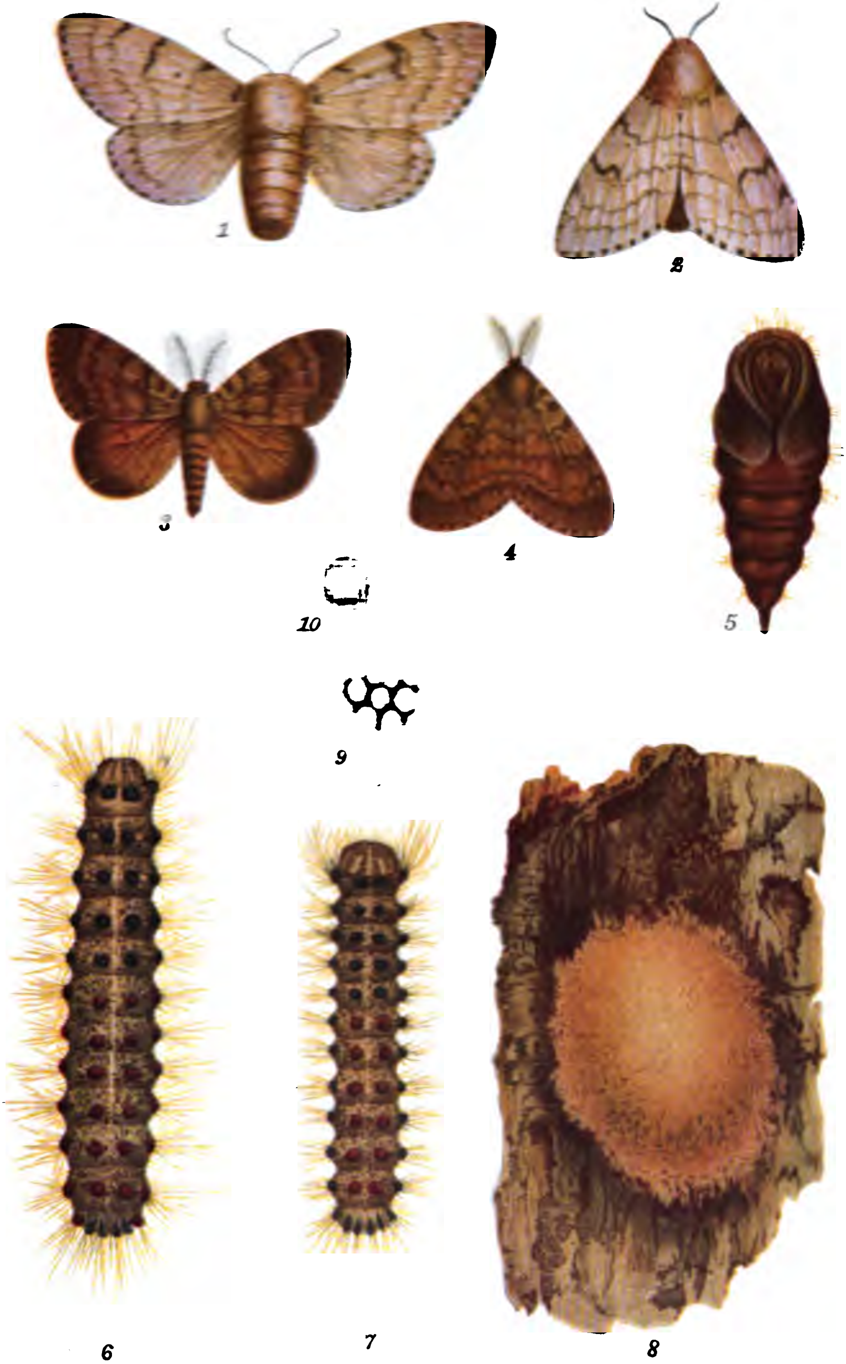
Andrews, E. A.: Breeding Habits of Crayfish, Am. Nat., 1904, vol. xxxviii. The Keeping of Crayfish for Class-room Use, Nat. Study Ser., 1906, vol. ii. The Young of the Crayfishes, Astacus and Cambarus, Smithsonian Cont. to Knowledge, 1907, vol. xxxv.

Herrick, F. H.: Natural History of Lobster, Bull. Bureau of Fisheries, 1909, vol. xxix.

Ortman, H. E.: The Crawfishes of the State of Pennsylvania, Memoirs Carnegie Museum, Pittsburgh, Pa.

Pearl, Raymond, and **Clawson, A. B.:** Variation and Correlation in the Crayfish, with Special Reference to the Influence of Differentiation and Homology of Parts. Octavo, 70 pages, 8 text figures. Published 1907. Price $1.00. Carnegie Publication.

PLATE II



Gypsy Moth, Porthetria Dispar, Linn. (After Massachusetts State Board of Agriculture.)

1, female with wings expanded; 2, female in resting position; 3, male with wings expanded; 4, male in resting position; 5, pupa; 6, dorsal view of one of the larger caterpillars, presumably a female; 7, dorsal view of one of the smaller full-grown caterpillars, presumably a male; 8, egg cluster on a piece of bark; 9, a few eggs greatly enlarged; 10, one egg still more enlarged.

N
diffe
dass
king
qua
ver
dist
des

(
thi
thr
In
an
at
th
st
h
t
a
I

CHAPTER XIX.

INSECTS.

Number.—If the estimate of over 400,000 as the number of the different species of insects is even approximately true, they form a class of animals more numerous than all of the rest of the animal kingdom. While it is evident that one cannot hope to become acquainted with such a large number of separate species, it is, however, very easy to recognize an insect. Inasmuch as they have world-wide distribution and play such an important role in the life of man, it is desirable to know a few general facts about them.

General Characters.—One of the most remarkable facts concerning this numerous class of animals is their marked similarity. There are three distinct regions easily recognized—head, thorax and abdomen. In general the head bears the organs of special sense, of prehension and of mastication; the thorax, the organs of locomotion; the abdomen, the organs of reproduction. Metamerism as shown for the crayfish is present although so greatly modified that one must study the embryonic stages to be able to locate the segments in the head region which consists of at least five primitive segments, while three are present in the thorax and eleven in the abdomen. There is an exoskeleton of chitin as in crayfish, although it is more flexible. Insects when first hatched frequently do not resemble the adult until they have passed through a change known as metamorphosis (Plate II).

THE HONEY BEE.[1]

The honey bee is suggested as the form to be studied in the laboratory. But for those who prefer the grasshopper, the text of the bee will serve for comparison.

There are nineteen general orders (see page 301) of insects, and the one regarded as the highest, the Hymenoptera, is the one to which bees, wasps, ants and ichneumon-flies belong. Many students of animals regard the body of these insects as being more highly specialized than the body of the frog, bird or even man. This is particularly true of the ant.

---

[1] Students are urged to read "The Life of the Bee," by Maeterlinck in connection with their study.

Kinds.—There is but one species of the honey bee, Apis mellifica, which is the same whether found in a hollow tree far from human habitation or in an apiary near a large city. Bees are not domesticated like the horse but retain all of their natural instincts. The honey bee was introduced into the United States as early as 1638. Bee-keepers recognize several subspecies or races of the honey bee, such as "Italian," "German," "Caucasian," etc.

The Honey Bee Colony.—A colony of bees is the general expression used among bee-keepers, but in attempting to describe scientificially the social habits of animals, the term colony is restricted to such groups of animals as have an actual structural union like the hydroids (Fig. 125, *A*). In place of the word colony, biologists employ the term community to describe the varied and interesting life of the higher insects: bees, wasps and ants (see page 211).

The bee colony consists of three individuals, a single queen, many drones and thousands of workers (Fig. 147).

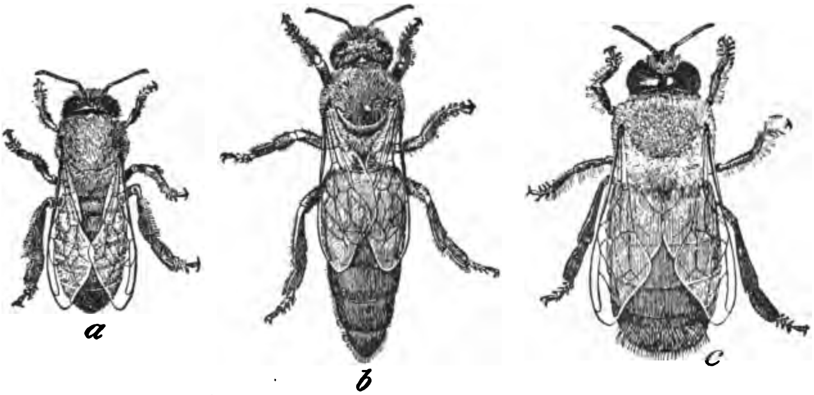


Fig. 146.—The honey bee: *a*, worker; *b*, queen; *c*, drone. Twice natural size. (Phillips, United States Department of Agriculture.)

The Queen.—The single queen in each colony is the largest of the three. Her contribution to the welfare of the colony is the laying of the eggs from which young queens, drones and workers develop. "The number of eggs laid by the queen varies from a few daily, in early spring and late fall in the northern regions, to about 1500–2000 a day at the height of the egg-laying season. Under special conditions, usually artificially produced by the bee-keeper, she may lay as many as 4500 or 5000 eggs a day and maintain this rate for several days. *The weight of the maximum number that can be laid in a day is equal to about twice the weight of the queen at any time during the period, indicating a marvelous rapidity in metabolism.*" The life of the queen is three or four years in length, with a few cases on record of seven years.

Drones.—These are the male bees, and it seems strange that there should have developed a social organism with but one female and several hundred males, as is shown by the bees. The usual social unit of one male and one female thus becomes highly modified in the bee colony. Compare these relations with those that exist in the seal (page 211).

A single drone mates with the queen but once in the life of the queen. As a result of this act the drone dies. The remaining drones in the colony are heavy eaters and contribute nothing to the welfare of the colony unless the old queen dies and a virgin is hatched or introduced into the colony. In this case she must mate before she can lay eggs. When the food in the colony becomes scarce there is reason to believe that the drones are first starved and then removed from the hive by the workers.

Workers.—The workers are females with undeveloped sexual organs. "They are justly called worker bees. These bees feed the growing larvæ; clean, guard, and ventilate the hive; build comb, gather nectar, pollen, water and propolis, and, in fact, do all the work of the hive, except that normally they lay no eggs."

The length of time that workers live varies with the season. During the active period of summer, six weeks is long enough for them to become old, and frayed-winged individuals are commonly seen dead outside of the hive. Workers hatched in the fall live until the spring brood of workers is ready to care for the colony.

Structure of the Honey Bee.—The bee is like a specialized crayfish in its general body plan. There are the same jointed appendages (Fig. 146), with the addition of wings; there is an exoskeleton hardened by chitin and a grouping of the somites into the three body regions, head, thorax and abdomen.

Internally similar organ systems are present, the details of which belong to laboratory study. However, three special features are presented because they are of great importance in understanding bees. These are their manner of respiration, of reproduction and the making of honey.

Respiration.—The method of respiration in the honey bee introduces us to a plan entirely distinct from the use of the gills of the crayfish or the lungs of the frog. In Fig. 147 is shown part of the tracheal air tubes and sacs in the body of the bee. These are connected with the surface of the body at definite places and the opening through the exoskeleton is called a spiracle. These spiracles admit fresh air and permit the contained air to escape through the action of the muscles of the body. The tracheal air tubes ramify throughout the body, even penetrating into the brain. By this means oxygen is carried to all of the cells of the body.

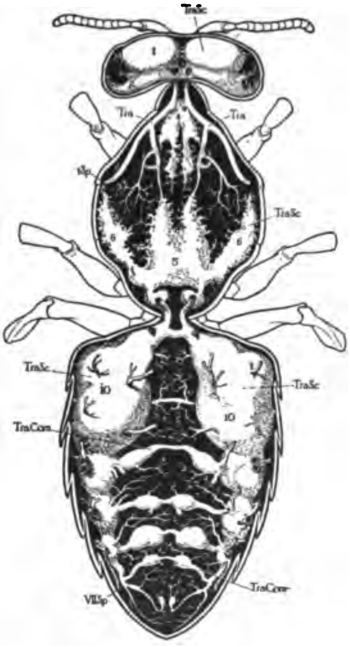


Fig. 147.—Tracheal system of worker, showing lateral and ventral parts as seen from above, with dorsal sacs and trunks removed in both thorax and abdomen. *Tra*, trachea; *TraSc*, tracheal sac; *TraCom*, tracheal commissure; *ISp*, first spiracle; *VII Sp*, seventh spiracle. (Snodgrass, United States Department of Agriculture.)

The tracheal system of air tubes in the bee is an illustration of the respiratory structures present in the body of all insects. Each order of insects exhibits modifications in the arrangement of the tracheal system, but the method of furnishing air to the cells is the same.

Reproduction.—The virgin queen takes her nuptial flight during which she mates with a drone. In this act she receives spermatozoa which are stored in the sperm receptacle (Fig. 148, *Spm.*). The queen does not mate a second time, so that the sperms received constitute the only available supply during the entire egg-laying life of the queen which is often four or five years. The sperms, then, remain alive in the sperm-receptacle of the queen although they are "so highly specialized that they can take no nourishment." It has been estimated that a single queen may lay 1,500,000 eggs which would require that an enormous number of sperms be received at mating.

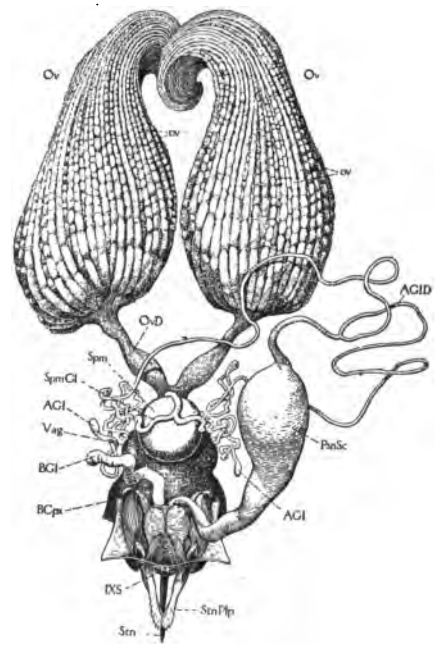


Fig. 148.—Reproductive organs, sting and poison glands of queen, dorsal view. *AGl*, acid gland of sting; *AGlD*, duct of acid gland to sting; *BCpx*, bursa copulatrix; *BGl*, alkaline gland of sting; *Ov*, ovary; *OvD*, oviduct; *PsnSc*, poison sac of sting; *Spm*, spermatheca; *SpmGl*, spermathecal gland; *Stn*, sting; *StnPlp*, palpus-like appendages of the sting; *Vag*, vagina. (Snodgrass, United States Department of Agriculture.)

The eggs that hatch into queens or workers are fertilized and those that produce drones are unfertilized. By far the greater number of eggs laid by the queen are fertilized, for the workers greatly outnumber the drones. It is difficult to explain how the queen can lay both fertilized and unfertilized eggs. If it be an instinct, then it is a most highly specialized one, for the even composition of the colony is maintained from year to year even when a new queen from a different race is introduced into the hive.

The method by which drones are produced is termed *parthenogenesis* or *asexual reproduction*. This is quite common among the insects. Parthenogenesis should not be confused with fission in paramecia or budding in hydra, for the drones develop from an egg that is just like all of the other eggs except that it is not fertilized.

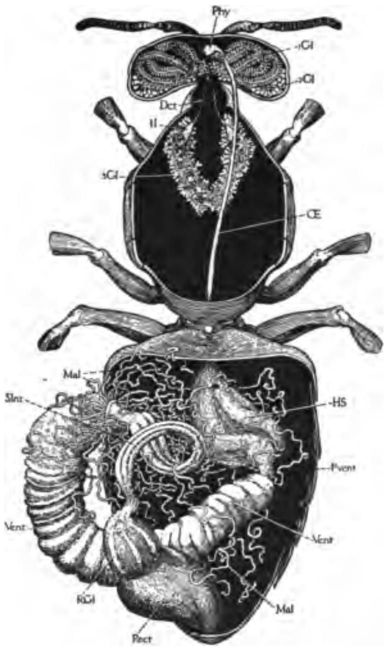


FIG. 149.—Alimentary canal of worker (*Phy-Rect*), together with pharyngeal glands (*1Gl*), and salivary glands of head (*2Gl*) and of thorax (*3Gl*), as seen by cutting body open from above and pulling the ventriculus (*Vent*) out to left. *Dct*, duct; *1Gl*, large pharyngeal gland in anterior part of head; *2Gl*, salivary gland in head; *3Gl*, thoracic salivary gland; *HS*, honey stomach; *Mal*, Malphigian tubules; *OE*, esophagus; *Phy*, pharynx; *Pvent.* proventriculus; *Rect.*, rectum; *RGl*, rectal glands; *Slnt*, small intestine; *Vent*, ventriculus. (Snodgrass, United States Department of Agriculture.)

Honey.—The annual crop of honey in the United States alone is estimated to be worth about $17,000,000 as food for man. Man has been eating honey since ancient times and critically studying all phases of the life of the bee for the past forty years. But as yet he can describe in only a general way how the bee makes honey.

The collecting of honey is done entirely by the workers who suck the nectar from plants. This they swallow and store in the honey stomach (Fig. 149, *HS*), until the return to the hive, when it is deposited in a cell in the honey comb. "Here it is ripened into honey. This ripening consists in the removal of the surplus moisture, the water in honey usually being about 20 per cent. of the total, while nectar is often over 60 per cent. water. The chemical composition of nectars has not been sufficiently studied and, indeed, this is a hard problem, because of the difficulty of obtaining sufficient quantities without modification. Enough is known, however, to allow the assumption that the ripening process also includes the changing of sucrose (cane-sugar) into invert sugars (dextrose and levulose)."

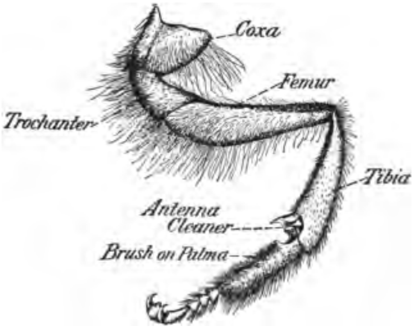


FIG. 150.—Left foreleg of a worker bee. (Casteel, United States Department of Agriculture.)

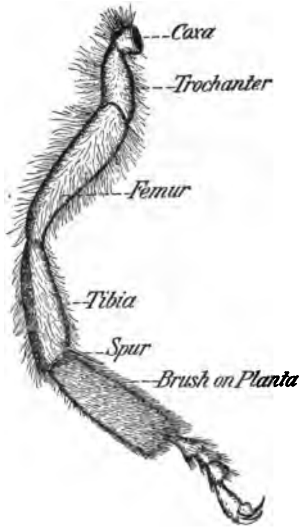


FIG. 151.—Left middle leg of a worker bee. (Casteel, United States Department of Agriculture.)

Pollen Collecting.—Closely associated with the gathering of nectar is the work in collecting pollen. This introduces one to a highly specialized series of instincts that may be compared to the special responses of other animals as illustrated on pages 291 and 293.

The three pairs of legs and the hairs on the body and legs are the main structures that need to be considered. Figs. 150–153 show the legs and their hairs. The tibia of the last pair of legs is especially modified to hold pollen and the term pollen-basket or corbicula is given to this region.

"A very complete knowledge of the pollen-gathering behavior of the worker honey bee may be obtained by a study of the actions of bees which are working upon a plant which yields pollen in abundance. Sweet corn is an ideal plant for this purpose, and it will be used as a basis for the description which follows.

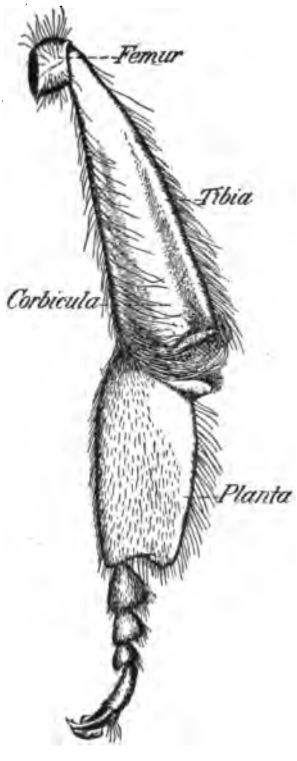


FIG. 152.—Outer surface of the left hind leg of a worker bee. (Casteel, United States Department of Agriculture.)

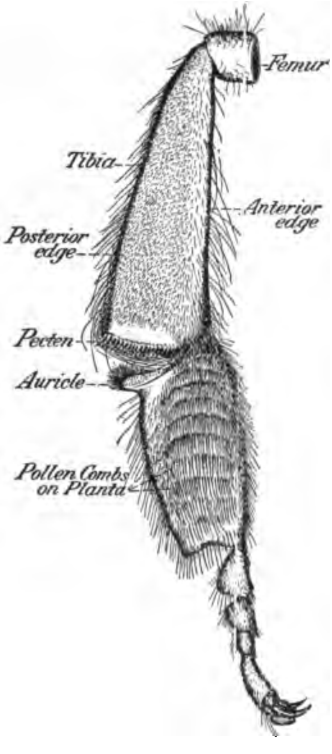


FIG. 153.—Inner surface of the left hind leg of a worker bee. (Casteel, United States Department of Agriculture.)

"In attempting to outline the method by which pollen is manipulated the writer wishes it to be understood that he is recounting that which he has seen and that the description is not necessarily complete, although he is of the opinion that it is very nearly so. The movements of the legs and of the mouth parts are so rapid and so many members are in action at once that it is impossible for the eye to follow all at the same time. However, long-continued observation, assisted by the study of instantaneous photographs, gives confidence that the statements recorded are accurate, although some movement may have escaped notice.

"To obtain pollen from corn the bee must find a tassel in the right stage of ripeness, with flowers open and stamens hanging from them. The bee alights upon a spike and crawls along it, clinging to the pendent anthers. It crawls over the anthers, going from one flower to another along the spike, being all the while busily engaged in the task of obtaining pollen. This reaches its body in several ways.

"As the bee moves over the anthers it uses its mandibles and tongue, biting the anthers and licking them and securing a considerable amount of pollen upon these parts. This pollen becomes moist and sticky, since it is mingled with fluid from the mouth. A considerable amount of pollen is dislodged from the anthers as the bee moves over them. All of the legs receive a supply of this free pollen and much adheres to the hairs which cover the body, more particularly to those upon the ventral surface. This free pollen is dry and powdery and is very different in appearance from the moist pollen masses with which the bee returns to the hive. Before the return journey this pollen must be transferred to baskets and securely packed in them.

"After the bee has traversed a few flowers along the spike and has become well supplied with free pollen it begins to collect it from its body, head, and forward appendages and to transfer it to the posterior pair of legs. This may be accomplished while the bee is resting upon the flower or while it is hovering in the air before seeking additional pollen. It is probably more thoroughly and rapidly accomplished while the bee is in the air, since all of the legs are then free to function in the gathering process.

"If the collecting bee is seized with forceps and examined after it has crawled over the stamens of a few flowers of the corn, its legs and the ventral surface of its body are found to be thickly powdered over with pollen. If the bee hovers in the air for a few moments and is then examined, very little pollen is found upon the body or upon the legs, except the masses within the pollen-baskets. While in the air it has accomplished the work of collecting some of the scattered grains and of storing them in the baskets, while others have been brushed from the body. In attempting to describe the movements by which this result is accomplished it will be best first to sketch briefly the roles of the three pairs of legs. They are as follows:

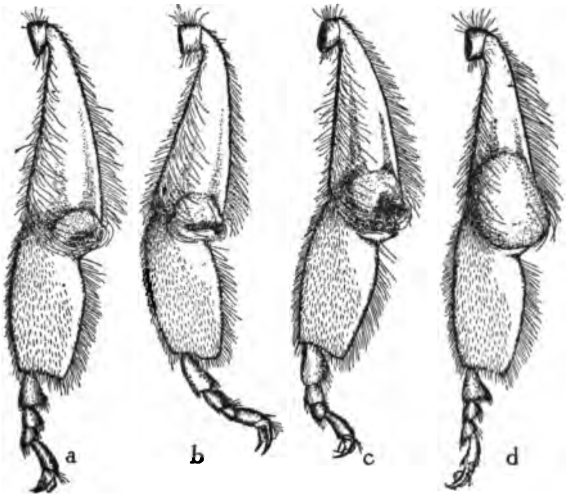


Fig. 154.—Camera drawings of the left hind legs of worker bees to show the manner in which pollen enters the basket. *a* shows a leg taken from a bee which is just beginning to collect. It had crawled over a few flowers and had flown in the air about five seconds at the time of capture. The pollen mass lies at the entrance of the baskets, covering over the fine hairs which lie along this margin and the seven or eight short stiff spines which spring from the floor of the corbicula immediately above its lower edge. As yet the pollen has not come in contact with the one long hair which rises from the floor and arches over the entrance. The planta is extended, thus lowering the auricle. *b* represents a slightly later stage, showing the increase of pollen. The planta is flexed, raising the auricle. The hairs which extend outward and upward from the lateral edge of the auricle press upon the lower and outer surface of the small pollen mass, retaining it and guiding it upward into the basket. *c*, *d*, represent slightly later stages in the successive processes by which additional pollen enters the basket. (Casteel, United States Department of Agriculture.)

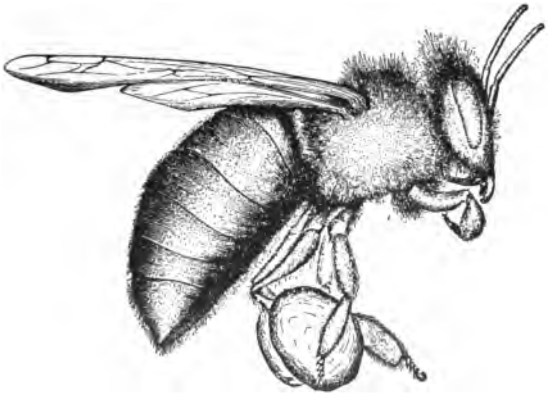


Fig. 155.—A bee upon the wing, showing the position of the middle legs when they touch and pat down the pollen masses. A very slight amount of pollen reaches the corbiculæ through this movement. (Casteel, United States Department of Agriculture.)

"(*a*) The first pair of legs remove the scattered pollen from the head and the region of the neck, and the pollen that has been moistened by fluid substances from the mouth.

"(*b*) The second pair of legs remove scattered pollen from the thorax, more particularly from the ventral region, and they receive the pollen that has been collected by the first pair of legs.

"(*c*) The third pair of legs collect a little of the scattered pollen from the abdomen and they receive pollen that has been collected by the second pair. Nearly all of this pollen is collected by the pollen combs of the hind legs, and is transferred from the combs to the pollen-baskets."

The details connected with the activities of the mouth parts and the detailed action of each pair of legs illustrate a very complex series of reflexes that help one to understand why the bee is regarded as such a highly specialized animal. This account of the honey bee has been taken from the following:

REFERENCES.

CASTEEL: The Behavior of the Honey Bee in Pollen Collecting, Bureau of Entomology, Bulletin No. 121.

PHILLIPS: Beekeeping.

SNODGRASS: The Anatomy of the Honey Bee, Bureau of Entomology, Technical Series No. 18.

CHAPTER XX.

SOME BIOLOGICAL ADAPTATIONS.

Adaptation.—It is so difficult to mark off sharply the habits of organisms that it seems wise to describe some of the general conditions of adaptation. Each organism is limited in size and occupies a definite place in nature. The mere fact that this statement can be made implies that each organism is fitted to live in the place where it is found. Here surrounded for the most part by inanimate particles it lives its life. In one sense all nature constitutes its environment, but in a more restricted sense its immediate surroundings most deeply affect the various parts of the organism.

Animals and plants are adapted to living in the water, on land, at sea level, on the mountain top, in the tropics, in the Arctic circle, in short, everywhere on our globe. But when man attempts to transfer plants and animals from one environment to another then the extent of adaptation is appreciated. Most organisms become so thoroughly adapted that they cannot be transferred: the polar bear cannot live in the tropics for any length of time, the palms of the South die in the North unless housed. Examples could be indefinitely multiplied.

One must keep in mind that each organism begins life in a single cell and that each organ as it assumes its work in the body of the organism gradually acquires certain physiological ways of working that add to the success of the whole organism with the result that adaptation is really a problem that must go to the protoplasm for its final analysis. Besides the changes involved in day and night, in temperate regions there is the seasonal adaptation, conspicuously illustrated in winter when leaves are shed and birds migrate to warmer climates. The habits of each group of animals indicate that some prefer the night time for foraging while others do best during the day. At the bottom of all of these varied and numerous adaptations are specific differentiations in cell structure or cell physiology.

With the diversified physiographic conditions that obtain on the globe it is to be expected that organisms will have developed many unusual methods of gaining a livelihood. The profligacy of nature in producing such vast numbers of individuals has resulted in her constantly turning loose more individuals than can find a foothold. The struggle for food is the most satisfactory explanation for the origin of some of these peculiar habits. Coöperation began in nature with the first pair of animals. This pairing springs from a universal necessity for all of the higher animals, namely, to insure the perpetuation of the species; for this the united energies of the two are required, especially where parental care exists. This means that the individual is not the social unit but that two animals that have paired either temporarily or permanently constitute the unit. In those animals that exercise no care of their young, there is usually an enormous drain on the parents in producing a large number of eggs and sperms which compensate in part for the lack of parental care. The necessity of having a place to live whether it is temporary or lasting implies ownership of that place for the time being; with some animals this simply means a limited occupancy, while with others possession is exclusive. The social unit, the pair, prevails in all classes of animals above the protozoa; and as the scale of complexity is ascended it becomes more predominant.

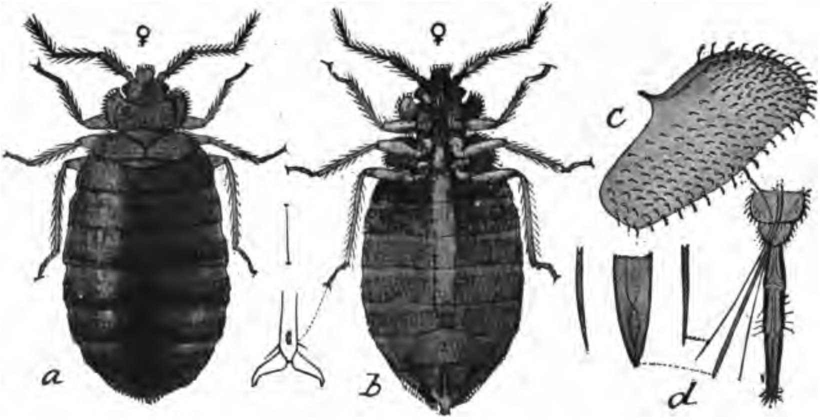


Fig. 156.—The bed-bug (*Cimex lectularius*). *a*, adult female gorged with blood; *b*, the same from below; *c*, rudimentary wing pad; *d*, mouth parts. *a* and *b*, much enlarged; *c* and *d*, highly magnified. (Marlatt.) Relapsing fever and kala azar are carried by the bed-bug. (Rosenau.)

Under conditions which are but partly understood both animals and plants become adapted to live in relationships quite distinct from these just described. Such special terms, as parasitism, symbiosis and community life, are commonly used to describe these acquired adaptations. The following is but a brief outline of some of their habits, and the student is urged to read in addition Van Beneden's *Animal Parasites and Messmates* and Jordan and Kellogg's *Evolution and Animal Life*, Chapters XVI to XIX.

PARASITISM.

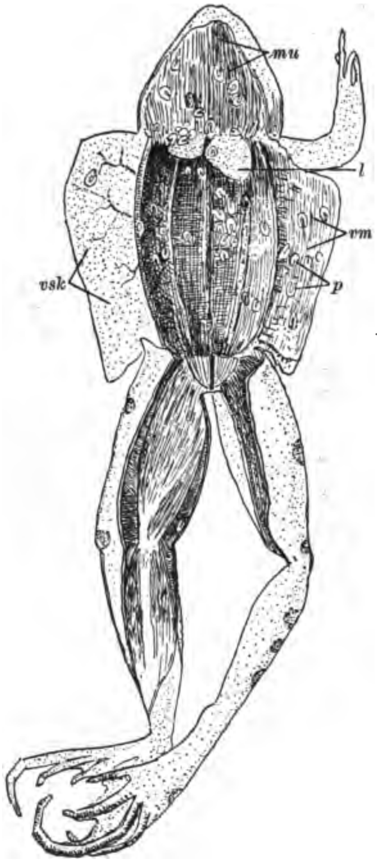


FIG. 157.—View of the ventral surface of the frog after the removal of the cœlomic viscera, showing numerous encysted flukes. *Clinostomum marginatum.* *l*, lung; *mu*, muscles of floor of mouth; *p*, flukes in place; *vm*, ventral muscles of cœlomic cavity; *vsk*, skin of ventral cœlomic wall. (Osborn.)

The term "parasitism" was first employed to describe those who sat around the table of the rich in ancient Greece receiving their invitation through fawning and flattery. When the word was used to describe a similar relation among animals it was applied to animals that have taken to a thievish existence as unbidden guests in or on other organisms. Our knowledge of the facts of parasitism goes back into the sanitary codes of the Jews and Egyptians which declared as unclean such animals as the pig, rabbits, and dog, animals now known to be especially infested with parasites, and it is only within recent years that our sanitary laws have made pork a clean meat. During the middle ages the school men perplexed themselves with quaint hypotheses as to the time and place of the introduction of parasites into man. The idea that life could spring suddenly into existence was a fruitful suggestion for their origin, and it was not until the eighteenth century, when the life history of one of the flesh-eating flies was completely worked out, that scientific men began to suggest that parasites arose from free-living animals. This discovery led to a truer knowledge of the origin of parasites and from then on until today there is not a parasite known that cannot be traced in origin to some antecedent life.

Classification of Parasites.—Biologists would be glad if they could work out an exact classification for the plants and animals that lead a parasitic life, but such instances as the following show how futile is the attempt: Animals like horse-flies and mosquitoes which come and go may be termed *temporary;* while the bird-lice which pass their entire life on the bird are called *permanent.* The fleas, ticks, dodders, mistletoes, and others confine their relations to the outside of their host, and the term *external* is applied; while the

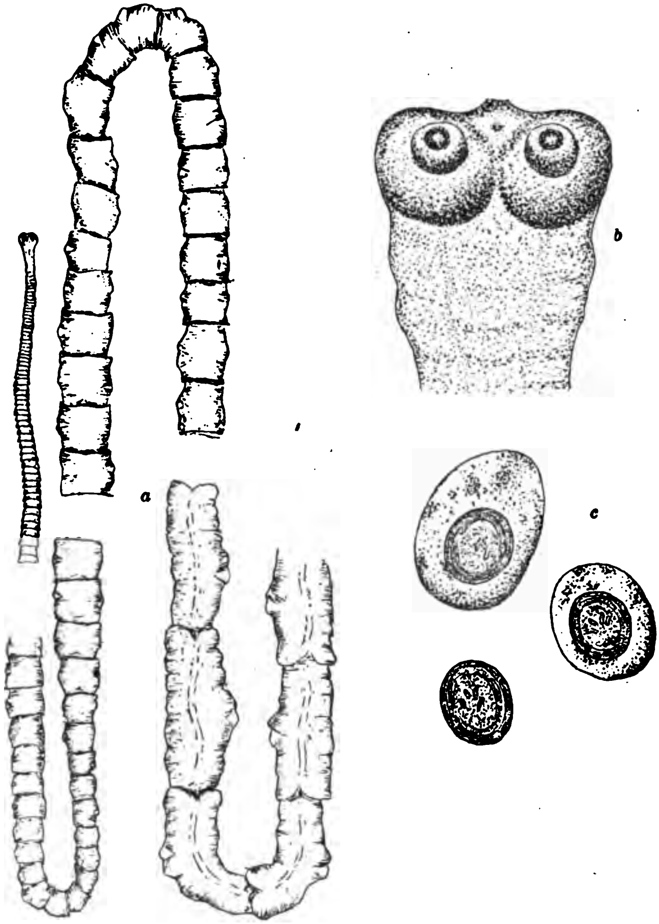


Fig. 158.—*Tænia saginata.* *a*, natural size; *b*, much enlarged; *c*, ova much enlarged. (Simon.)

tapeworm of cat, dog, or man is entirely within the body and so should be called *internal.* This life history affords another method of classification. The leech is parasitic in the *adult,* while the larva of the fresh-water clam always passes a part of its development encysted in the gills of some fish, typifying a class of animals parasitic only during their *larval* existence. From this same stand-point there are those animals also which either *complete* their *life* in *one host,* such as the pup worms found in young seals, or those that demand *several* hosts. Of this latter class is the organism malaria which spends part of its life in the blood of man and the remainder in the body of the anopheles mosquito. Or the malarial parasite may be classified as one that is dependent for its existence upon its hosts, and thus termed an *obligatory* parasite; while any parasite which temporarily lives within or upon a host and can exist without utilizing the parasitic habit a part of the time is called a *facultative* parasite. The parasitic bacteria belong in the main under this latter term. The effect on the parasite affords still another form of classification. Some parasites, like the leech, mosquito, or trichinella, show very little effect as a result of this habit; while the great majority are permanently and noticeably degenerated as a result of their mode of living. The most important aspect of this question is the effect of parasitism, first upon the parasite and then on the host. As a general statement the parasitic habit tends to weaken the self-dependence of the parasites. This is shown in many ways other than the inability of the parasite to live alone and thrive. Some of the parts of the body actually disappear although present in the young animal. The marine crab is infested with a conspicuous example known as *Sacculina.* This parasite has a complete set of all the organ systems characteristic of its class while it leads a free-swimming life, but as soon as it becomes parasitic its appendages, food canal, sense organs, and nervous system are lost, the body consisting essentially of reproductive tissue, a system which never degenerates. The tapeworm has no alimentary canal and only the remains of a nervous system. Other examples could be given to show that there is an actual loss of organs that the parasites need when living alone. The parasite loses these parts because it has no use for them; thus failure to use an organ tends to its obliteration.

Extent of Parasitism.—It is a well-known fact that all of the larger animals harbor or may harbor many parasites, but as soon as careful studies are made the smaller animals also are found to be parasitized, even to the protozoa. One recent expert says that "it is not a too sweeping generalization to state that every living thing, large enough to contain another living thing, is subject to invasion by parasites. The protozoa, themselves single cells, often play the part of host to smaller protozoan cells, and parasites often infect the nucleus of ameba, paramecium, vorticella, and other types." It is difficult to make the word parasite convey an exact meaning, for we know that many trees harbor hundreds of inescts; that the fly, mosquito, and others occasionally bite us. From the fly to the tick is but a short step, and the tick is surely a parasite. The sheep in the pasture feeding upon the grass and the fox killing mice for her young are in the broad sense living on other living things. These cases are not regarded as parasitism, although the habit is essentially the same. The word parasite is best limited to such plants and animals as literally take up their residence for a time upon some other form of life which is the host. This means that the parasite is always smaller than the host, although it may be a higher organism. In most instances parasites are simpler in structure than their host, as the tapeworm in dog, or the ameba in man.

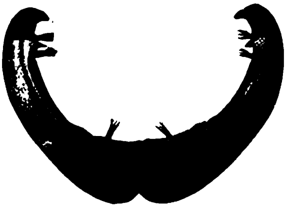


Fig. 159.—Axe-head glochidium of the clam, Lampsilis (*Protera alata*), anterior end view. In the larval stage the glochidium of certain fresh-water molluscs lives from nine to thirty-six days as a parasite in fish and this is a necessary stage in its life history. (Le Fevre and Curtis.)

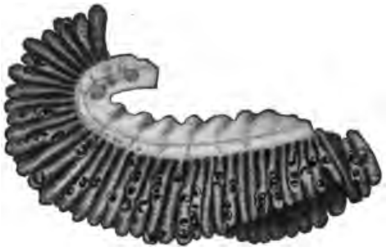


Fig. 160.—Gill of yellow perch infected with glochidia of the clam (*Lampsilis ligamentina*), showing distribution upon the gill as a whole and the appearance of the cysts. They are also found on the fins. (Le Fevre and Curtis.)

Parasitic Habits.—It is impossible in the limits of this book to do more than illustrate the most conspicuous habits of parasitic organisms. Parasites that are parasitic in the *larval stage only* are well illustrated by the habits of the fresh-water clams. When the embryos of these clams have passed through the segmentation stages they grow into a form known as the *glochidium* (Fig. 159). This is a stage in the development of the clam quite unlike the adult. It bears the same relation to the clam that the tadpole does to the frog. When the glochidia are set free in the water they sink to the bottom. They are entirely incapable of locomotion although the adductor muscle causes the valves to close frequently, and in response to mechanical stimuli the valves close firmly and remain closed. As the fins of a fish brush over the hooked glochidia they become attached to the fish. Here they remain as parasites from two to ten weeks, the length of time depending upon the species of clam. The glochidia which do not have hooks become attached to the gills (Fig. 160), entering through the mouth of the fish as water is taken in for respiration. During the time that the glochidia remain as parasites on the fish they are metamorphosed into small clams. Unless the glochidia become attached to the fish they die. The fresh-water clams of several species thus illustrate a specialized habit in which fish have become necessary to the clam's growth to maturity.

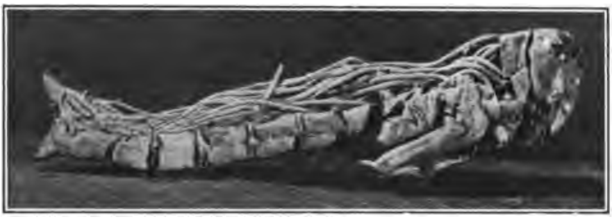


FIG. 161.—Second larval stage of "horse-hair" worm in body of grasshopper.

A similar parasitic habit is shown in the "horse-hair" worm shown in the body of the grasshopper (Fig. 161). These worms are not parasitic when adult and are commonly seen in springs, watering troughs, etc. The eggs hatch into a small larval stage that usually enters the body of some insect. After passing through certain changes it is set free in the water. This condition is known as the second larval stage. The second larval stage enters the body of an insect or fish where it continues to live until it comes to look much like the adult worm; but before the adult stage is reached this second larval stage leaves the body of its host and becomes a free-swimming worm in the water. Here it quickly reaches sexual maturity and is able to set free eggs, thus completing the life cycle. The worm shown in the body of the grasshopper is the second larval stage of the "horse-hair" worm.

---

[1] Le Fevre and Curtis, Studies on the reproduction and artificial propagation of fresh-water mussels. Bull. Bureau Fisheries, 1910, xxx, Document No. 756.

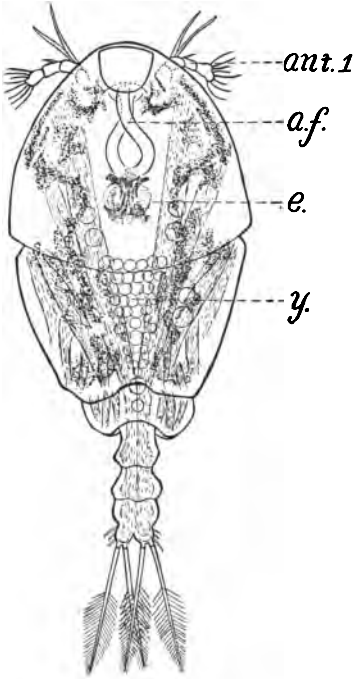


FIG. 162.—*Salminicola edwardsii.* Dorsal view, free-swimming stage. × 173.5. *a.f.*, attachment filament; *ant.1*, first antennæ; *e*, x-shaped eye; *y*, yolk. (Fasten, Journal of Animal Behavior.)

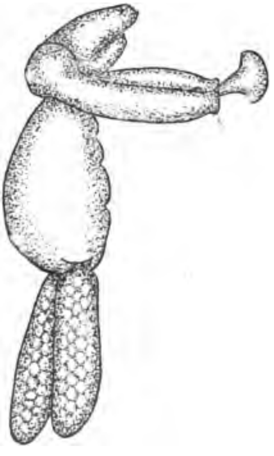


FIG. 163.—Adult fish-louse, *Salminicola edwardsii.* Compare the structures present with those in Fig. 162. (Redrawn from C. B. Wilson.)

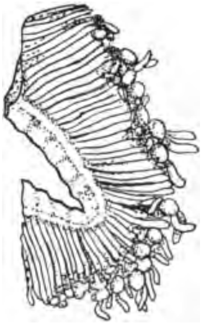


FIG. 164.—"Fish-lice" attached to gill of fish.

A group of parasites familiarly known as "fish-lice" are widely distributed among both salt- and fresh-water fish. There are 136 different species, all of which are parasitic during their *adult life only*. The species Salminicola edwardsii is very common, although found exclusively on the brook trout. It lives attached to the fins and gills of the fish (Fig. 164). In its adult stage the female undergoes a great deal of degeneration (Fig. 163). During the larval stage the young animal swims actively about and possesses the usual organs found in the group of crustacean animals to which it belongs (Fig. 162). The specialized habits of the "fish-lice" are the reverse of the clam and the "horse-hair" worms, but the fish has come to be just as necessary to the fish-lice as it is to the clam. These two parasites also illustrate the effect of parasitism upon the parasite, for the worms show practically no change; while the fish-lice undergo a large amount of degeneration.

The following study presents a phase of parasitism that is very important not only because it illustrates the *complicated life-history* of certain parasites but also because it indicates how difficult it is to prevent the spread of such parasites.

White-pine Blister Rust.[1]—The organism which causes the white-pine blister rust lives in one stage upon the pine and in the other on the leaves of currant or gooseberry bushes. It is a plant that belongs to the fungus group known by the technical name of Cronartium ribicola. Like most fungus plants there are produced spores which are carried by the wind. When the spores of a certain stage in the life of this parasite fall upon the white-pine, they begin to grow in the bark. Here they may live from one to six years with no external sign of their presence. The first indication of the presence of these parasites is the swelling of the bark at the point of infection. Fruiting bodies push their way through the swollen tissue. As these ripen numerous spores like bright yellow powder are discharged. Each spore is capable of reproducing the disease but they cannot grow upon the white pine. To distinguish these spores from a second kind of spore, they are called peridermium spores (Fig. 165).

The peridermium spores are blown about by the wind, and if one falls upon the leaf of a currant or gooseberry plant, it is able to attack that leaf. This small spore "sends its root-like germ tube into the soft tissues of the currant leaf, and there it spreads within the leaf tissues until it has attained a certain amount of strength." In about two weeks there appear on the under side of the currant leaf tiny masses, hardly larger than a pin-head, of fine, orange-yellow powder.

---

[1] The White-Pine Blister Rust, Perley Spaulding, Farmer's Bulletin, No. 742.

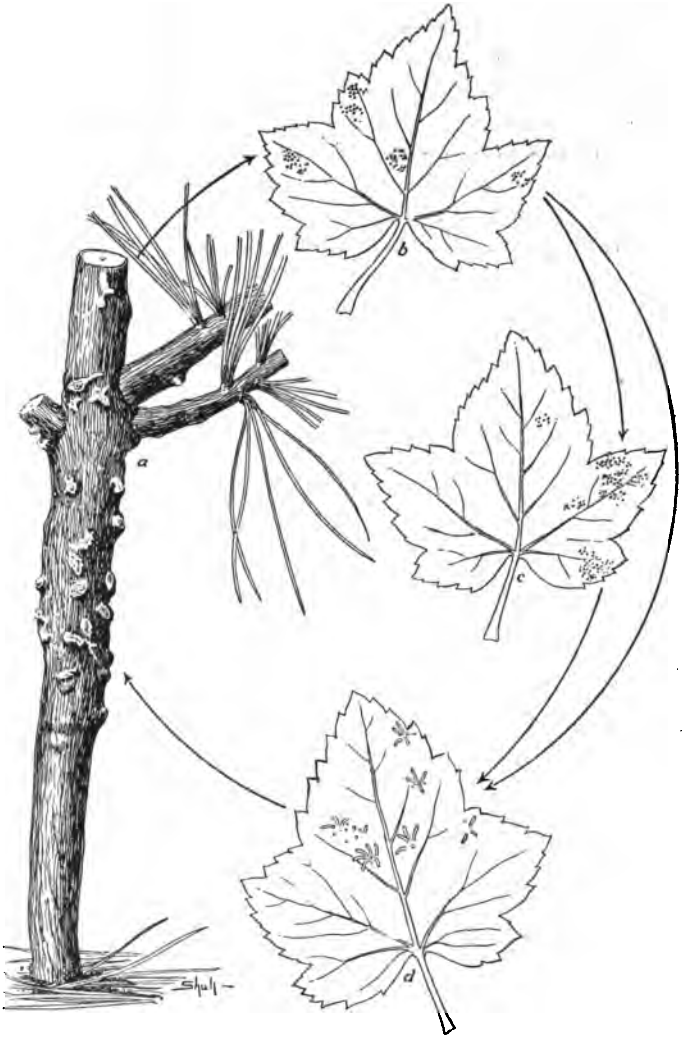


Fig. 165.—Diagram indicating the life circuit of the causal fungus of the white-pine blister rust. *a*, blisters on pine in May and early June, from which the disease spreads to currant or gooseberry leaves and produces the early summer stage, *b;* thence it may spread to another currant leaf and produce there a second crop of the early summer stage, *c;* or it may produce the late summer stage, *d;* in this stage, in the fall, it infects neighboring white pines, which may or may not include the pine (*a*) which bore the blisters that started the outbreak the preceding spring. (Spaulding, United States Department of Agriculture.)

These new spores are quite distinct from the peridermium spores and hence are called uredospores.

The uredospores may be called the repeating stage, as these spores can only reinfect currant or gooseberry leaves. This they may go on doing every two weeks from the latter part of July until the leaves drop off in the fall. At this time a third form of spore is grown which appears in the same spots that have been earlier producing uredospores. "The new form appears as a group of 3 to 10 of short, stout threads, not over a quarter of an inch in length and usually are in small circles. Upon these threads are produced spores of another distinct form. These are the teliospores."

The teliospores cannot repeat their development on the currant or gooseberry leaves, but must fall upon the bark of young white pines. These spores now can germinate, penetrate the bark and grow in the inner layers. The life cycle is complete. The presence of numerous wild currant bushes in forests of white pine is a source of real danger.

The white-pine blister rust illustrates what is known as the alternation of generations in the life cycle of parasites (compare with hydroids, page 157). The complex life history of malaria is another illustration of the same principle of adaptation (page 220).

Why are Parasites Sometimes Very Numerous?—The student will find an answer to his question, "Why are parasites more numerous in certain parts of the country or during certain years?" in the following explanation of the life history of the spring grain aphis. In order to answer this question accurately, it is necessary to know in detail the habits of the animal about which the question is asked. The explanation, however, is to be found in the relation which certain conditions such as food, temperature, time of breeding and enemies bear to each other. The following, then, is a typical scientific explanation of the abundance or scarcity of parasites. "The spring grain aphis (*Toxoptera graminum*) is present every year in greater or less abundance and is kept under control by its natural enemies, more especially by a tiny black and brownish four-winged fly (*Lysiplebus tritici*). The aphis gives birth to young from spring until fall, but during mild winter weather young are born as long as such weather continues, while the parasite remains dormant. The aphis begins to breed whenever the temperature rises to 45° or 50° F. during the day, while for the parasite it must be at least 10° warmer. Under normal weather conditions during winter and spring the aphis starts in the spring from the eggs (winter eggs), and there are enough parasites, which have wintered over in the bodies of the aphis and emerged therefrom, to destroy so many of this aphis that it cannot increase rapidly enough to become injurious; consequently there is no trouble. But there comes a winter during which the temperature is warm enough to enable the aphis to breed continuously, and it thus becomes abundant by spring. If the weather turns cold during the winter the pest ceases to breed and serious depredations are averted, but if, as is more often the case, a cold backward spring follows an abnormally warm winter, then the pest continues to breed while its enemies remain inactive and the result is that the former becomes so enormously abundant that wheat and oats are destroyed over large sections of the country before the parasite can increase sufficiently to overcome it." (Webster.)

Symbiosis.—There is another set of relations, where two dissimilar organisms live together for their mutual benefit, which is conveniently described by the term symbiosis, which simply means a living together. These relations occur between animal and plant, animal and animal, and plant and plant. For example the lichen is a simple grayish plant growing on fences, stones, etc. If a botanist is asked to classify the lichen, he usually hesitates because the plant consists really of two distinct plants that have become so intimately associated that neither lives alone. The grayish color is due to the effect of the whitish fungi (Fig. 104) which grow over and around some green cells. The fungous elements belong to the same class of plants as the mushrooms, while the green cells are intimately related to the plant that often gives a greenish tint to the bark of trees (Fig. 82, *A*) and to the plants growing in ponds and known as pond scum. These two distinct plants live, intimately associated and it is difficult to see how the relation is harmful to either, and in fact it is regarded as decidedly beneficial. The second example is where two animals live together. The hermit crab, a form related to the lobster, protects itself by occupying empty snail shells into which it backs in case of danger (Fig. 167). In the Mediterranean Sea there is frequently found on such a snail shell a large sea anemone, which is permanently attached to it. The sea anemone belongs with the corals, jelly-fish, and hydras—a much simpler and lower class of animals than the crabs. The sea anemones are provided with numerous stinging organs that have a paralyzing effect which renders them inedible. Now the hermit crab is eaten by predaceous fish, but not when it carries the sea anemone around on its back. The sea anemone gathers its food from the water but it is stationary in habit and can secure only what the water brings to it.

The hermit crab moves about from place to place, thus enabling the sea anemone to secure food more easily. Such are some of the obvious reciprocal benefits.

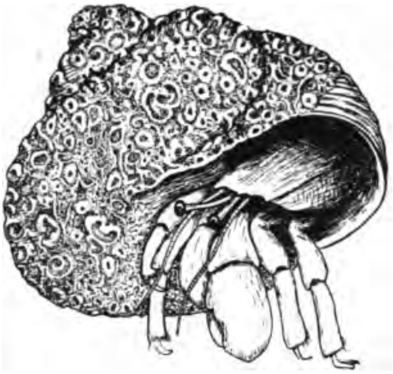


FIG. 166.—Hermit crab occupying a fossil snail shell. The surface of the snail shell is mostly covered by the encrustations of numerous small tube-forming worms. These hermit crabs live in holes near the water on the Bermuda Islands. To this species of hermit crab this fossil snail shell is but a convenient and safe retreat and serves the same purpose that the shell of a present-day snail would if available.

Between true parasitism and real symbiosis there are very many social relations that cannot be properly described by either term; nor is there any sharp line of demarcation between them but an indistinct gradation from one to the other. These symbiotic and semisymbiotic relations are not very numerous in nature and are hard to explain when the benefits are not obvious (Fig. 167), in fact some writers believe that all of these are parasitic relations. Degeneration does not appear to be a conspicuous part of the symbiotic relations. The motive for the habit seems to be greater protection and ease

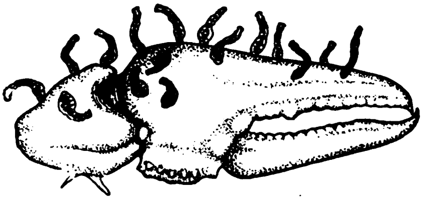


FIG. 167.—These small worms are found attached to the exoskeleton of the crayfish. They feed upon unicellular algæ and diatomes so do not derive any food from their host. In this instance these worms, *Branchiobdella pulcherrima* and *B. instabilia*, cannot be regarded as parasitic nor are they symbiotic in the usual meaning of this relationship. Drawn from material collected in Lake Clear, Adirondacks.

in gaining a livelihood. It is conceivable that some of the relations are of the same character as in human affairs where an individual is continually being assisted without returning the compliment. Certain barnacles have a habit of burrowing into the skin of whales, the barnacle gains all of its food from the water, and is carried from place to place by the accommodating whale which surely cannot be benefited in any way by these minute animals and apparently has no way of preventing the relation. It seems a bit extreme to be always trying to figure out some utility for all of the varied relations we observe. They may be regarded as some of Nature's partly successful experiments; at any rate they are unusual and eccentric and are given here to show that there is a wide range of relations in the social life of animals.

Community Life.—The social life of the honey bee (page 188) is an illustration of this specialized social habit. A higher degree of community life is found among some of the ants where in addition to the sexless worker there are to be found soldiers and slaves. An interesting account of the complicated family life of the ants is found in Chapters XIX–XXVII of Wheeler's book on Ants.

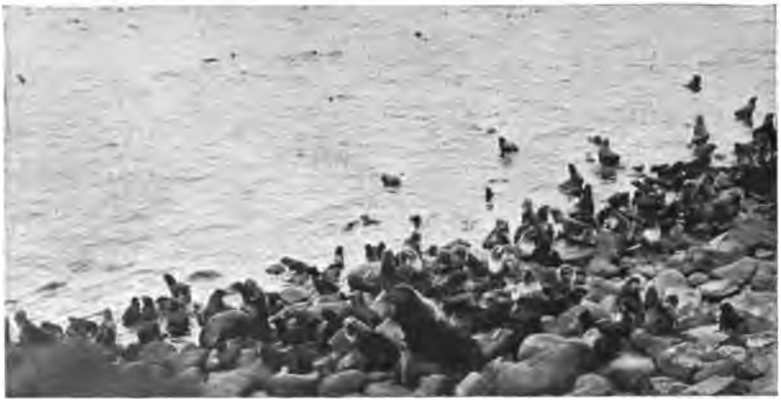


FIG. 168.—A harem on Gorbatch rookery; the bull with many cows and newborn pups, July, 1914. Each harem consists of a single bull and from 20 to 100 cows. (Parker.)

Gregariousness.—Among the birds and mammals the habit of forming flocks for all or part of the year is common. In some of the flocks a form of polygamy exists, the King of the flock killing the other males in combat. Such a collection of animals is obviously one in which protection against enemies is the dominant reason for the association (Figs. 168 and 169).

In this very brief survey of some of the adaptations of organisms, particularly animals in their several habits, the many structural adaptations and the whole question of color has intentionally been omitted because of lack of space. It is important to understand that these many relations represent acquired, though perfectly natural, habits that have reached their present high state of differentiation through a series of gradual adaptations. In seeking to explain the phenomena of parasitism and symbiosis the factors in the immediate environment are the causes to be studied. The community of the ant and bee has become so highly specialized that they could not exist if each individual pair were compelled to live apart, and the same is true of some of the parasites which live in two or more hosts like the tapeworm or the rust, when one of the hosts fails the species is unable to perpetuate its kind. While, on the other hand, there are parasites that can live attached to a host for a time and equally well when separated from it. This is the case with many of the parasitic bacteria which suggests that bacteria now non-parasitic may gain access to some animal and cause a disease new to science.

FIG. 169.—Murres or arries on Walrus Island, July 16, 1914. (Osgood, Preble and Parker, Bulletin of the Bureau of Fisheries.)

CHAPTER XXI.

SOME BIOLOGICAL FACTORS IN DISEASE.

The Role of Biology.—The skilled investigation of many men along the lines of technical research is fast revealing to us the part played by animals and plants in disease. No text-book can be up to date upon this topic for any length of time because so much that is new is continually being reported in the scientific journals. The part played by biology in these revelations is interesting and important. To biology belongs the study of the several pathogenic organisms in their relation to other organisms, in their habits and in their life history. The sources of infection, methods of carrying disease, and the fate of the disease-causing organism are strictly biological problems which are again studied in medicine because of their importance. Biology also emphasizes the fact that the so-called biological diseases have a well-recognized history associated with specific changes in the pathogenic organisms which are revealed as the disease progresses. These modern studies are more wonderful and strange than any tale of fiction and would seem to belong to the realm of the miraculous were they not abundantly substantiated by experts in all civilized lands.

The pathogenic organisms have a definite life history that must be understood in order to prevent their gaining access to plants, animals, and man. It is important to recognize at the outset that these biological diseases occur generally in nature and often with disastrous results as the frequent epidemics in insects, in fishes, in trees, in potatoes, etc., indicate. Their manner of causing disease and all of its accompanying phenomena can be as well studied in plants as in animals. The knowledge that definite plants and animals cause disease is one of the most valuable facts in our modern civilization, for it supplies us with the exact information necessary to prevent disease. There is no way of measuring the money value[1] of a human life and yet hundreds are dying daily in the world at large from these biological, preventable diseases. Every agency should be utilized in spreading accurate information about disease and its prevention. It is impracticable in the following sections to describe all of the biological diseases, hence certain typical ones are selected to illustrate the general principles involved.

---

[1] Dr. A. R. Ward, of the Bureau of Animal Industry, estimates that the annual loss from diseases in cattle, sheep, and hogs is $212,000,000. The most of these diseases are preventable.

Rattlesnakes.—The rattlesnakes all possess a gland, located on both sides of the head and just below and behind the eye, which secretes a poison. From the anterior end of the poison gland extends a duct that opens at the base of the fang. The following account will serve to illustrate how the poison acts upon man. One of the attendants at the National Zoölogical Park was bitten, on August 17, by a diamond rattler (*Crothalus adamanteus*) on the middle finger of the left hand, proximal phalanx. The wound was immediately sucked and within fifteen minutes cauterized with a 1 per cent. solution of potassium permanganate. He was removed to a hospital where the following changes were found to be taking place. On admission the blood examination was: red blood cells, 4,600,000; white blood cells, 14,440; hemoglobin, 95 per cent. Eighteen hours after being bitten the blood examination was: red blood cells, 4,000,000; white blood cells, 16,000; hemoglobin, 75 per cent. On the fourth day the blood count was: red blood cells, 2,800,000; white blood cells, 14,000; hemoglobin, 60 per cent. The sixth day showed the lowest condition of the blood: red cells, 2,000,000; white, 12,000; hemoglobin, 45 per cent. After this date the patient began to recover

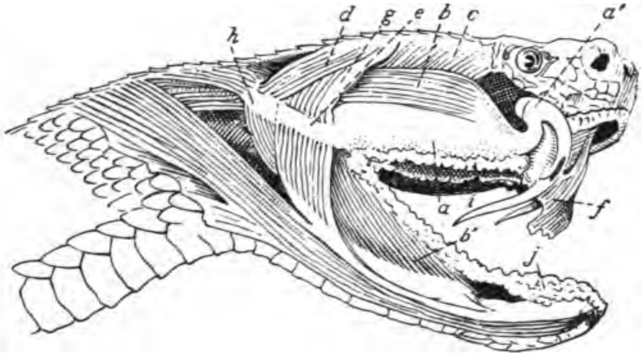
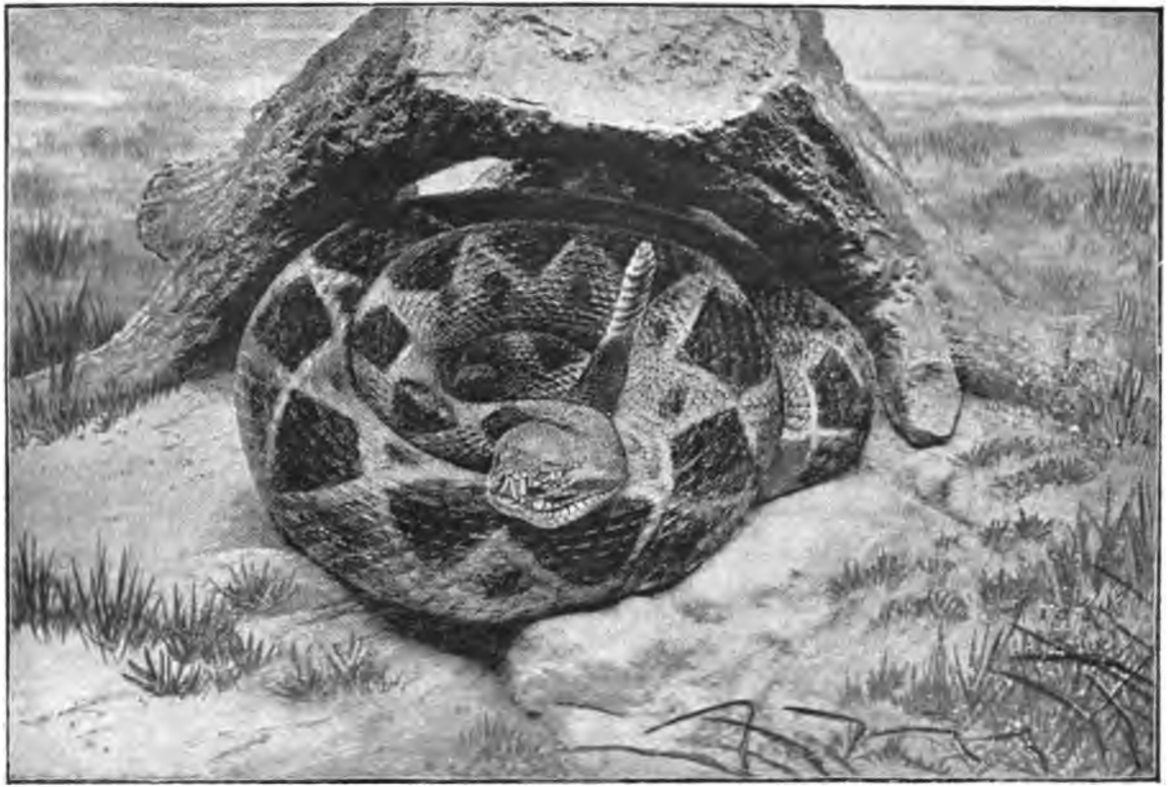


Fig. 170.—Poison apparatus of rattlesnake, venom gland, and muscles. Latera view. *a*, venom gland; *a'*, venom duct; *b*, anterior temporal muscle; *b'*, mandibular portion of same; *c*, posterior temporal muscle; *d*, digastricus muscle; *e*, posterior ligament of gland; *f*, sheath of fang; *g*, middle temporal muscle; *h*, external pterygoid muscle; *i*, maxillary salivary gland; *j*, mandibular salivary gland. (From Steineger, after Duvernoy.)

PLATE III



Diamond-backed Rattlesnake (*Crotalus Adamanteus*).

(From a Cast in the United States National Museum.)

and the cells of the blood gradually returned toward the normal, although six weeks after the snake had bitten him his blood count was only: red, 3,588,000; white, 9000; hemoglobin, 87 per cent.[1]

This case serves to indicate that there is a direct relation between the loss of the red blood cells and the bite of the snake. When the rattlesnake venom is injected into the blood of other mammals a similar result obtains. The breaking down of the red blood cells (chromolysis) is only part of the process but serves to indicate the definite result that comes to certain cells of the body when they come in contact with rattlesnake venom. As is well known, the bite is fatal in about 40 per cent. of the cases.

When man is bitten by a cobra the sequence of the pathological changes are distinct and easily recognized. In addition to the destruction of a large number of red corpuscles, the coagulating power of the blood is lost. Then follows a weakness in the legs and throat which soon develops into a paralysis of these parts. Finally the nervous centers that control breathing become involved and death occurs from respiratory paralysis.

The following Carnegie publications are the best references to rattlesnakes:

Noguchi, Hideyo: The Action of Snake Venom upon Cold-blooded Animals. Octavo, 16 pages. (Embodied in Publication No. 111.) Published 1904. Price $0.25.

Noguchi, Hideyo: Snake Venom: An Investigation of Venomous Snakes, with Special Reference to the Phenomena of Their Venoms. Octavo, xvii+315 pages, 33 plates, 16 text figures. Published 1909.

Although this volume refers more especially to the phenomena of snake venom, it covers much broader ground. The first fifty pages are devoted to a descriptive and systematic morphological and a distributional account of the poisonous snakes of the world, over 300 forms being enumerated, followed by a description of the poison apparatus. In a short chapter on the phylogeny of poisonous snakes the author states that the poison was probably the first of the specialized structures to appear, and that the elaborate, erectile, grooved fangs were of later development. The poison gland "is equivalent to, if not identical with, the parotid of the mammalia." The remainder of the work is given up to a consideration of the venom itself. There are chapters on its physical and chemical properties; symptoms of venom poisoning in man and in lower animals; and on the organism as a whole and upon specific organs and tissues, this latter subject being more fully treated than any other.

There follow chapters on artificial and natural immunity, with a technical discussion of antivenins. The final chapter, "Treatment of Snake Bites," contains a careful review of the various so-called antidotes with a scientific testing of their value. The monograph ends with a bibliography of about 400 titles and an index.

Loeb, Leo, in collaboration with Carl L. Alsberg, Elizabeth Cooke, Ellen P. Corson-White, M. S. Fleisher, Henry Fox, T. S. Githens, Samuel Leopold, M. K. Meyers, M. E. Rehfuss, D. Rivas and Lucius Tuttle: The Venom of Heloferma. Octavo, vi+244 pages, 38 figures. Published 1913. Price $1.50.

This volume contains a collection of papers dealing with the morphology of the venom gland, the physical and chemical properties of the venom, the action of the venom on vertebrate and invertebrate animals, as well as on certain cells and organs *in vitro*.

---

[1] The details of the case are given by Dr. C. S. White in Jour. Am. Med. Assn., 1910, lii.

Amanita.—Every year there are cases of mushroom poisoning which terminate fatally. In all of these serious cases the mushroom eaten is probably one of the amanita group. The general effect of the poison is to produce acute intestinal pains, a rise in the pulse and temperature often accompanied by delirium. The following is taken from Ford's recent study of the poisons in fungi: "It has been shown that the 'white' or 'deadly' *Amanita phalloides* contains a powerful hemolysin which acts upon a great variety of corpuscles, is destroyed by heating to 60° to 65° C. for half an hour and has the chemical composition of a glucoside containing $C=48.03$, $H=6.08$, $N=10.83$, $S=1.94$, $O=32.22$. This substance, judging from its destruction by heat and its susceptibility to the action of artificial gastric juice, cannot be held responsible for the symptoms seen in poisoning with the fungus in man. The species apparently owes its toxicity to the amanite toxin. Five cubic centimeters of the extract of *Amanita phalloides* killed a guinea-pig weighing 385 grams overnight, the same amount killed another guinea-pig weighing 420 grams in four hours, and a rabbit weighing 1035 grams succumbed within eighteen hours to a dose of this character.

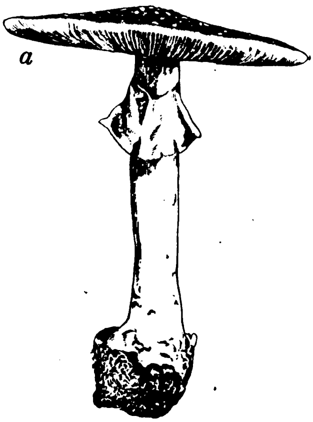


Fig. 171.—*Amanita phalloides.* (Rusby.)

"The *Amanita muscaria,* known popularly as the 'yellow' or the 'fly' amanita, owes its toxicity to the crystalline substance, muscarine, an ammonia derivative with the following chemical composition: $C_5H_{15}NO_3$. The muscarin extracted from this plant acts upon the nerve centers and the animal dies in convulsions. In addition to the muscarin this species contains also a hemolysin and an agglutinin, the latter acting like a glucoside."

The poison of the rattlesnake and the toxin of amanita are complex substances and already analyzed into two or more parts, and each of the components is responsible for a definite set of changes when introduced into man. In both instances the product is a normal growth of the organism.

The secretion from the poison gland of the rattlesnake is a poison which is a relatively simple chemical molecule that is broken down by digestion. This is the reason that it is safe to suck the wound caused by a poisonous snake. On the other hand, the toxin found in amanita is a complex chemical molecule that is not destroyed by digestion. In a general way this serves to distinguish between organic poisons and toxines.

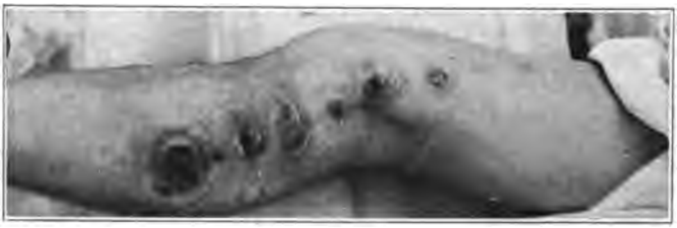


FIG. 172.—*Sporotrichosis.* Appearance of leg on entrance into hospital four months after initial lesion. (Hamburger.)

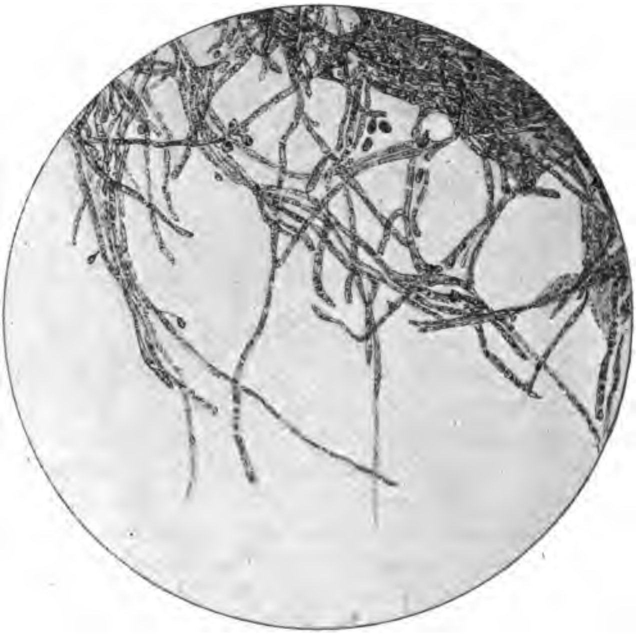


FIG. 173.—*Sporotrichium.* Four-day-old colony in plain bouillon; methylene blue oil immersion; showing septa in mycelium. (Hamburger.)

Sporotrichosis.—This is not a common disease in man, although the authentic number of cases has increased during the last few years. The disease is described here because it illustrates so well the relation of a definite organism to a specific pathogenic condition. Small ulcers occur usually on the leg and hand and from these ulcers may be cultivated a definite plant, as shown in Fig. 173. It grows exceedingly slowly when first cultivated in culture tubes. The growth of the second and third generations, however, is much faster. The organism consists of a branching mycelium with here and there spore-bearing branches. When cultures of the spores are injected into white rats and guinea-pigs abscesses form in some instances; and preparations from these abscesses show the presence of similar spores. In sections of the tissue similar spores are also found.[1]

In addition to this fungus (sporotrichium) found growing in the abscesses there are a number of other moulds and yeast-like plants that act in a similar manner. For these latter the term mycosis may be given (variously named blastomycosis, oidiomycosis, saccharomycosis), and the plant can be cultivated and studied and its morphology and life history fully determined in most instances. As soon as the plant can be removed or killed the ulcers heal.

Crown Gall.—Crown gall is a disease which occurs on a variety of plants and any part of root or shoot is liable to attack. It consists of an irregular growth which frequently becomes larger than the root or shoot upon which it occurs. In this growing mass of cells the conducting tissues are imperfectly developed. The way that the cells grow and their manner of dividing tend to place this disease quite apart from the usual diseases in plants, locating it in the category of the true tumors; it is believed by Smith that the conditions are similar to animal tumors.[2]

The cause of this disease has been an unsolved problem until the recent work of Smith and others. The successive steps employed in demonstrating that crown gall is due to a definite organism were the following: *First,* galls were crushed in beef broth, from which agar plate cultures were made, which were kept at temperatures varying from 20° to 30° C. The galls were thoroughly cleaned and modern antiseptic methods used. The *second* step was the finding of a definite organism, to which the name *Bacterium tumefaciens* was given, growing on the agar-culture plates (Fig. 174).

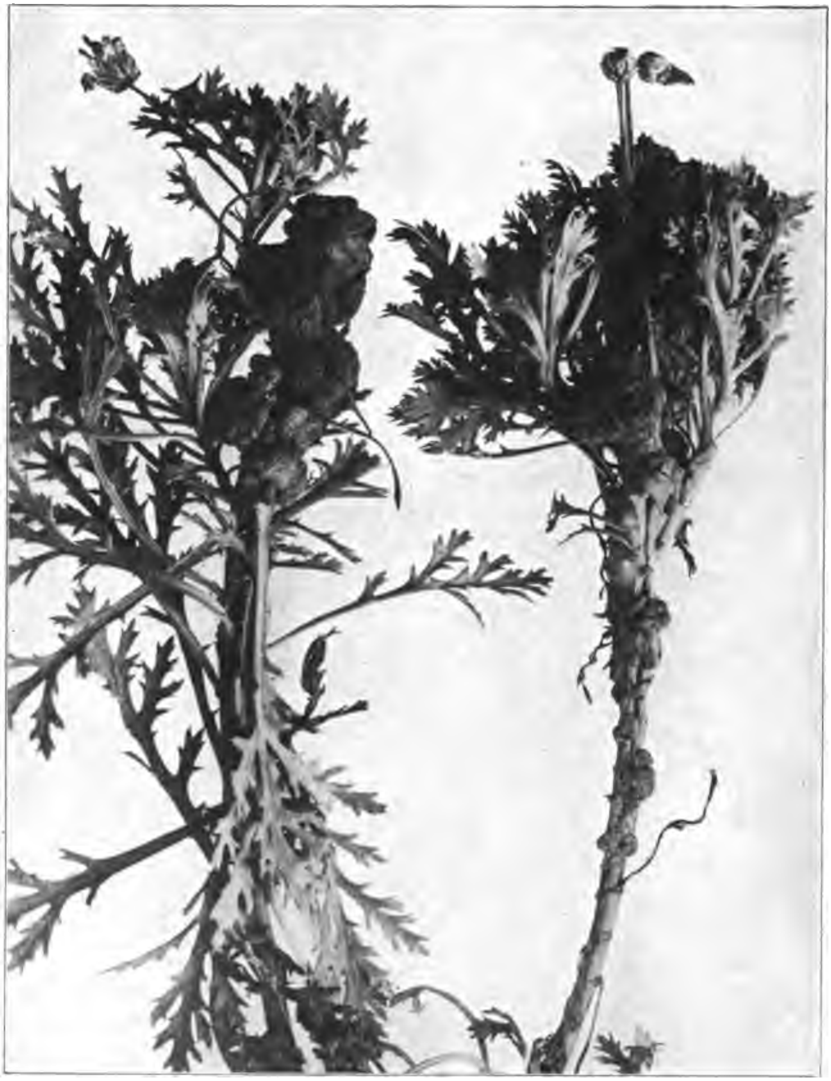
The *third* step was to demonstrate that the bacteria isolated on

---

[1] Sporotrichosis in Man, by Dr. W. W. B. Hamburger, Jour. Am. Med. Assn., 1912, lix.

[2] Smith, Brown, and Townsend: Crown Gall of Plants: Its Causes and Remedy, Bureau Plant Industry, Bull. No. 213. Smith, Brown, and McCulloch: The Structure and Development of Crown Gall: A Plant Cancer, Bureau Plant Industry, Bull. No. 255. Smith, E. F.: Further Evidence that Crown Gall of Plants is Cancer, Science, June 23, 1916, p. 871.

PLATE IV



A Natural Infection of Crown Gall in the Hot-house, which has probably resulted in the transfer of the germs by way of the gardener's hose in watering. (E. F. Smith.)

the agar plates would cause a similar growth when introduced into the tissues of a healthy plant. On June 1 inoculations were made into the stem of young healthy daisy plants growing in the pathological greenhouse. On June 18 a distinct elevation was visible at each point where an inoculation had been made.

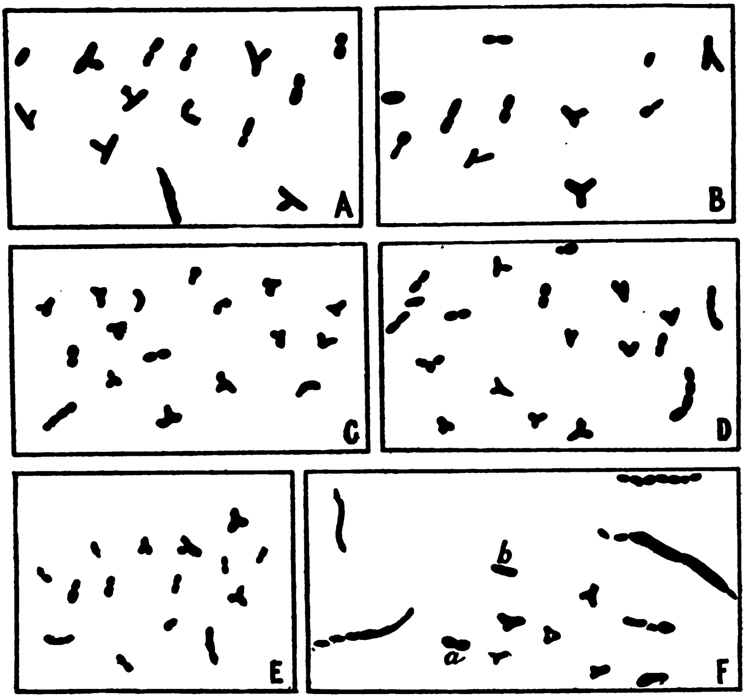


Fig. 174.—Bacterium tumefaciens. (E. F. Smith.)

The *fourth* step was the study of these new galls and the finding of the same organisms present. The infectious nature of these organisms was proved by inoculating healthy plants which in turn produced galls. This method of conclusively proving that a given disease was caused by a given organism was formulated by Koch.

The bacteria causing this disease are located inside the cells and it is the "stimulus of their presence which causes the cell to divide abnormally by throwing it out of balance." After the crown-gall tumor has been grown another series of changes begins. It seems that the soft tissues cannot be adequately nourished beyond a certain limit and decay sets in. "A variety of saprophytic bacteria and fungi take part in disintegrating the overgrown tissues. Among these saprophytic bacteria there are several white forms closely resembling the gall organism as grown on agar-poured plates, dendritic white forms, green fluorescent species, yellow species, orange species, pink species, etc."

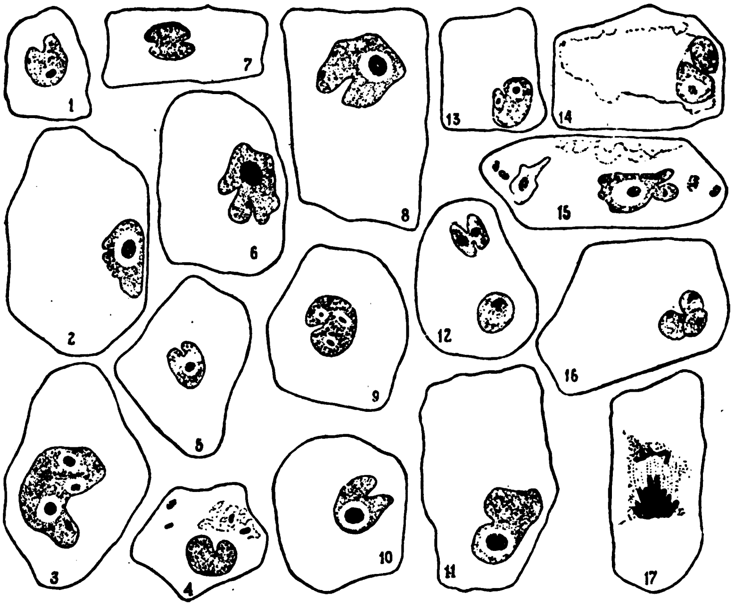
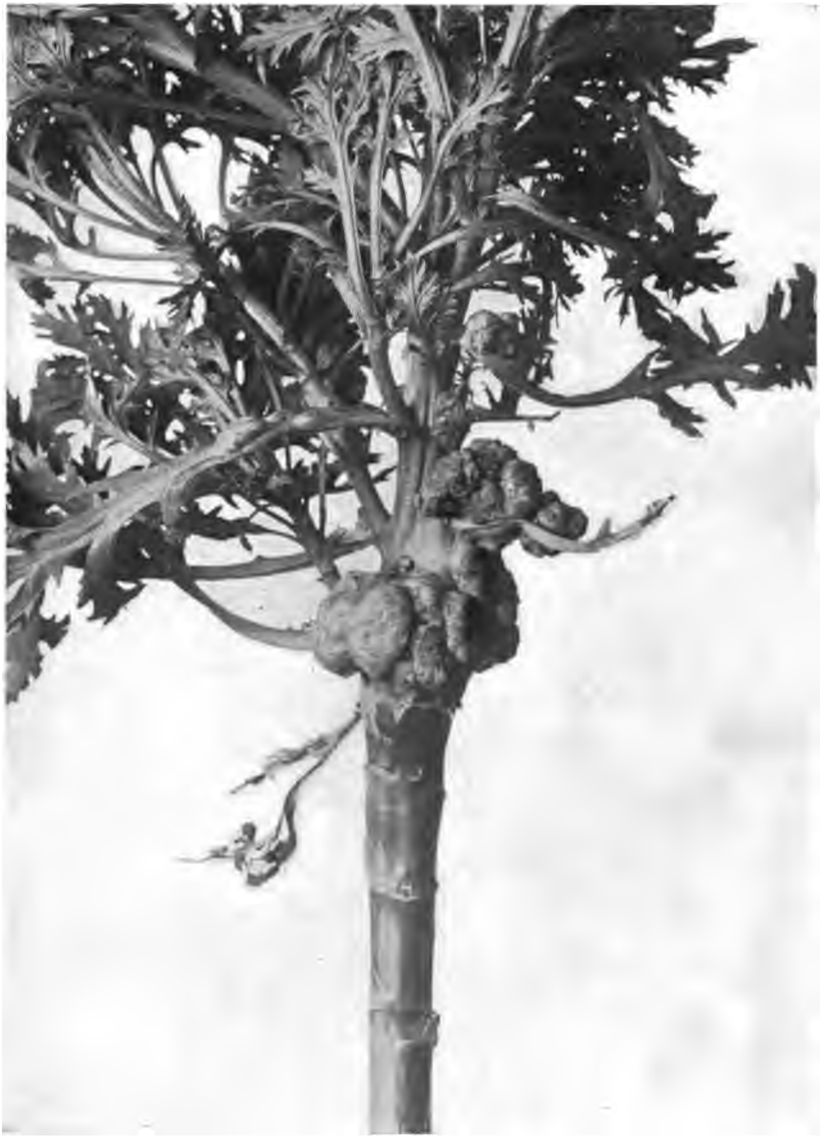


Fig. 175.—Nuclear divisions in crown gall. Nos. 1 to 16, cells showing stages of amitotic division; No. 17, mitotic division in which more chromosomes have passed to one pole than to the other. Material fixed in Flemming and stained with Heidenhain's iron hematoxylin. These cells show the abnormal conditions caused by the disease crown gall. (E. F. Smith.)

This disease serves to illustrate the method of determining the exact cause of a biological disease. The growth of the cells in crown gall is believed to be due to some stimulus produced by the bacteria as they live naturally, although as parasites within the cells. When the original disease reaches its limit a number of disintegrating bacteria begin to live upon this abnormal growth, with the result that decay sets in and parts slough off, causing an open wound. The organisms which bring about all of these undesirable results are definite living things which have a specific structure and life history.

Malaria.—When this disease was first recognized it was thought to be associated with bad air and was therefore named malaria. In

PLATE V



Plant Inoculated November 26, 1907, and Photographed March 8, 1908. (F. F. Smith.)

PLATE VI

Fig. 1

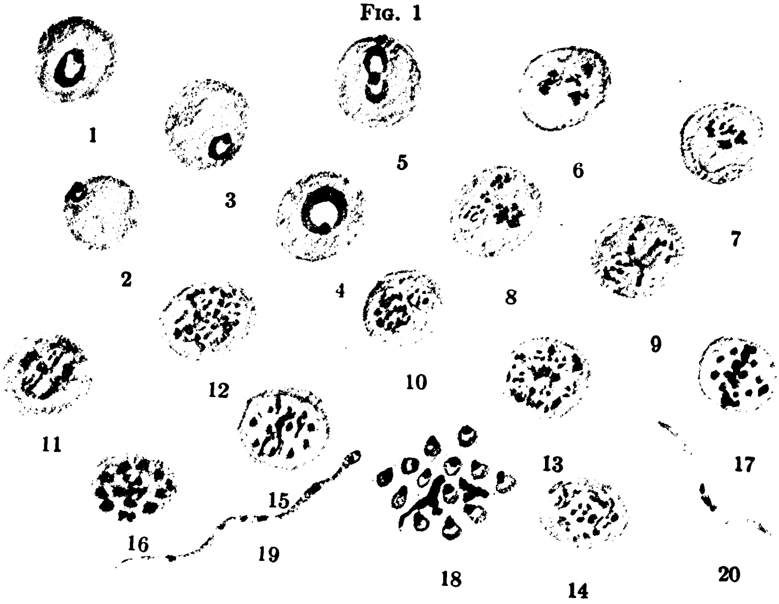
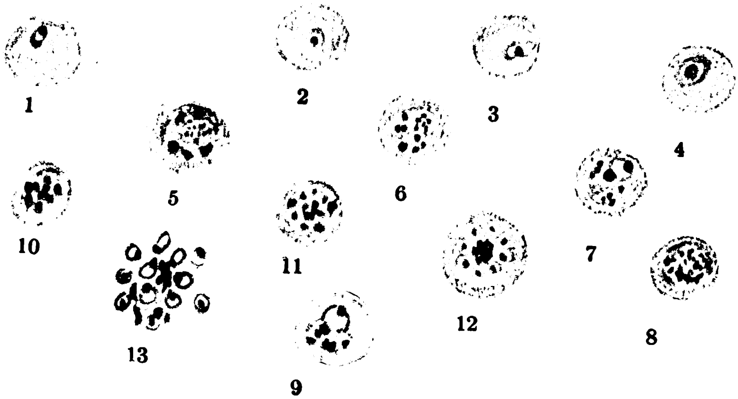


Fig. 2



CHARLES E. CRAIG, DEL.

Fig. 1.—Tertian Malarial Plasmodium. Stained by Oliver's Modification of Wright's Stain.

1 to 4. Ring forms of tertian parasite.
5. Ring form. (Conjugation form of Ewing.)
6 to 10. Pigmented organisms.
11 to 14. Nearly full-grown forms, showing diffusion of the chromatin.
15 to 17. Segmenting forms within red corpuscle.
18. Segmenting forms after destruction of red corpuscle.
19. Microgamete.
20. Sporozoite.

Fig. 2.—Quartan Malarial Plasmodium. Stained by Oliver's Modification of Wright's Stain.

1 to 4. Ring forms of quartan parasite.
5, 6, 7, 8, 9. Pigmented parasites.
10 to 12. Segmenting forms of quartan parasite.
13. Segmenting stage after destruction of red corpuscle.

Note.—Chromatin of nucleus stained red; protoplasm stained blue; vesicular portion of nucleus unstained.

1881 a French military doctor located in Algiers, Dr. Laveran, discovered in the blood of some malarial patients a new organism which he declared to be the cause of the disease. It was more than fifteen years after this discovery before definite information was available as to the source of this parasite in the human blood. The name *Plasmodium malaria* was given to this organism because of its supposed resemblance to some of the plasmodia-forming fungi. Authorities differ as to the exact number of malarial parasites but they all belong to the animal kingdom and are protozoa, class sporozoa, order hemosporidia (see page 148).

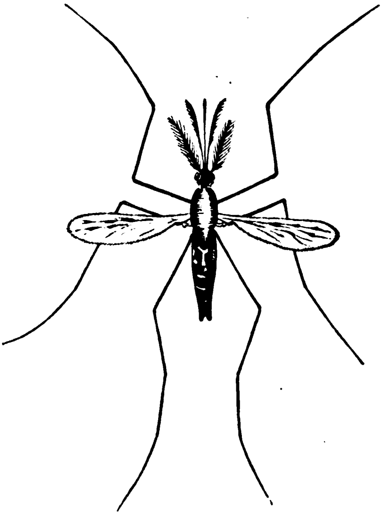


Fig. 176.—*Anopheles maculipennis*. Male. (Harrington.)

The malarial parasite is not able to complete its life history in the one animal (the frog, reptile, bird, or mammal) in which it first occurs, although it may live continuously for many months in the human body. The malarial plasmodium passes through a series of changes in the human blood as follows: The parasite penetrates a red blood corpuscle where it increases in size until it nearly fills the blood cell (Plate VI, Fig. 15). The time that it remains in the cell depends upon the kind of parasite, whether it be a one-day, a three-day, or a four-day form. At first the parasites are not very numerous, but after a few weeks their number is very great. As they all belong to the same original brood, they reach maturity in the blood cells at the same time and all are liberated from the blood cells at regular intervals. The fever accompanying this disease coincides with the liberation of a new swarm of parasites. The waste products of the parasite metabolism are also set free at the same time and assist in setting up disturbances in the body. After a time the parasites develop into two forms which are the sexual phases, the *macrogametocytes* and the *microgametocytes*. These cells do not fuse while the parasite remains in the human blood, but in the stomach of the anopheles mosquito. The fertilized cell makes its way into the lining epithelium of the intestine of the mosquito and comes to rest in the submucosa. Here it undergoes a series of divisions and ultimately gives rise to a stage known as a *sporozoite*. Some of these sporozoites make their way into the salivary glands and thence into the proboscis of the insect, from which they escape into the blood of man. The non-sexual forms of the parasite which are drawn into the stomach of the anopheles mosquito are destroyed. Should a culex mosquito suck up the blood of a malarial patient, all of the parasites are digested. And when an anopheles mosquito sucks the blood of a bird in which the organism *Plasmodium præcox* (causing estivo-autumnal fever) occurs the parasites are all digested.

Malaria is a disease that is distributed all over the United States and especially in the South. It can occur only through the patients being bitten by an anopheles mosquito which has the *Plasmodium malaria* in its salivary glands. It is a serious disease in some sections, and in 1900, 14,909 persons distributed throughout the United States died from it. There is no way of estimating the number who were incapacitated from working because of this disease. The writings of many of the Roman authors contain references to destructive epidemics of malaria, and the efforts to drain the deadly Campagna date back for many years. The first capital of Alabama, St. Stephens, which in 1810 was a thriving town, was literally wiped out of existence because of the prevalence of malaria. The present sanitary knowledge of malaria makes it entirely safe to live anywhere in the world if one simply protects himself from the bites of the anopheles mosquito by keeping behind a screen (19 meshes to the inch) after dark.

The Bacterial Diseases.—The several diseases (typhoid fever, tuberculosis, diphtheria, colds, pneumonia, gonorrhea, leprosy, tetanus, etc.), caused by some specific bacterium may be discussed under one heading in explaining their biological relations. Each disease has its own marked symptoms and recognizable germ, but so far as their biology is concerned all are similar. The bacteria gain access to our bodies and live parasitically, during which time the disease develops. The bacteria grow and multiply and carry on their own metabolism. *The result of this normal activity on their part is the production of poisons which disturb the cells of the human body; just what cells are interfered with depends upon the invading organism.* Each disease passes through several stages or cycles. The first of these stages is termed the incubation period and is the time that elapses between the entrance of the infection into the body and the day when the earliest symptoms appear. This idea of a period of incubation is well illustrated in the following table:

DISEASE WITH SHORT INCUBATION.

	Limits.	Usual time.
Diphtheria	2 to 7 days	2 days
Scarlet fever	1 to 8 days	3 to 4 days
Influenza	1 to 4 days	2 days
Erysipelas	3 to 7 days	4 to 5 days

DISEASE WITH LONG INCUBATION.

	Limits.	Usual periods.
Typhus fever	7 to 14 days	12 days
Typhoid fever	7 to 21 days	about 14 days
Chicken-pox	10 to 15 days	about 14 days
Smallpox	9 to 15 days	generally 11 or 12 days
Measles	7 to 18 days	generally 14 days
German measles	12 to 21 days	about 14 days
Mumps	14 to 21 days	about 16 days
Whooping-cough	7 to 14 days	about 10 days

The next stage is sometimes called the termination period, and there are various ways in which the disease comes to a close. The steady course may end abruptly, as in typhoid fever, and convalescence set in at once, or the decline may be very gradual, and it is difficult to say just when it stops. The last stage comprises the changes occurring in the return to ordinary health and is termed convalescence. Each bacterial organism living in this parasitic relation shows certain peculiarities as does the host, so that the conditions in any two cases are never exactly the same. The changes which the bacteria cause in the cells and tissues are likewise varied, so that general statements must be made; in one case ulcers appear, in another abscesses are formed, or certain glands are swollen, etc. In the study of the bacterial diseases great care has been exercised to definitely isolate the specific germ that is the cause of the disease and work out its life history and habits, as a result one can learn how to avoid infection by such germs. The number of persons dying annually from the bacterial diseases is very large, as one soon realizes from a study of the reports from any State board of health, but he also gains from such study the further important fact that all of these diseases are preventable. Whether the sanitary conditions of civilized nations will ever become so perfect as to prevent any considerable number of the bacterial diseases is a question, but it is the purpose of those who understand the wastefulness that comes from sickness and death due to these diseases to try to greatly reduce their number. The greatest work for medicine in the future is to be the prevention of disease instead of its cure.

The Filterable Viruses.—At present there are some thirty diseases of human, plant, and animal life which have been demonstrated to be due to organisms that can pass through a Berkefeld or Chamberland filter, and all of these are at present invisible with the highest powers of the microscope. Of the diseases which affect man the following may be mentioned: Foot-and-mouth disease, rabies, vaccinia, smallpox, yellow fever, dengue fever, trachoma, poliomyelitis, typhus fever, measles, and scarlet fever. In most of these diseases the unknown germ is transmitted by some intermediate host, such as mosquito or body-louse. In the next few years much that is new will be added to our knowledge of this group of diseases.

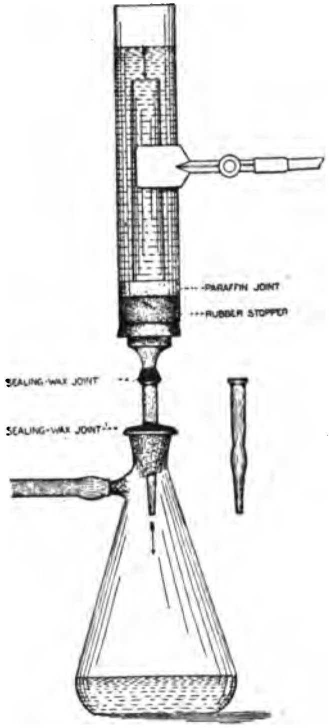


FIG. 177.—Chamberland filter. The central structure is an unglazed porcelain cylinder, through which the fluid is drawn by suction and filtered.

Tapeworms, Hookworms, and Others.—There are a number of highly developed animals that live as parasites mostly within the digestive canal in man and other animals. These are the well-known threadworms, tapeworms, hookworms and others. Their chief harm consists in either absorbing the nourishment taken by the host before it leaves the digestive canal or in the absorption of blood. The food being ready at hand in sufficient quantity, they have but to grow and reproduce until in some cases they become very numerous. It is not practical to make many general statements concerning this group of diseases because each animal has its own life history and mode of entering the body. Some, like the tapeworm, have a complicated life history, as already shown on page 158; while others, like the hookworm, readily pass from man to man without an intermediate

FIG. 178

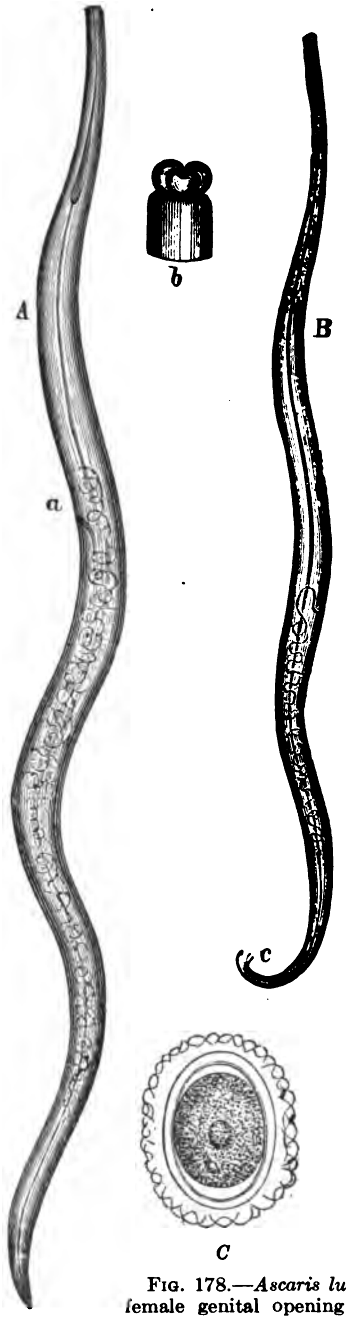


FIG. 179

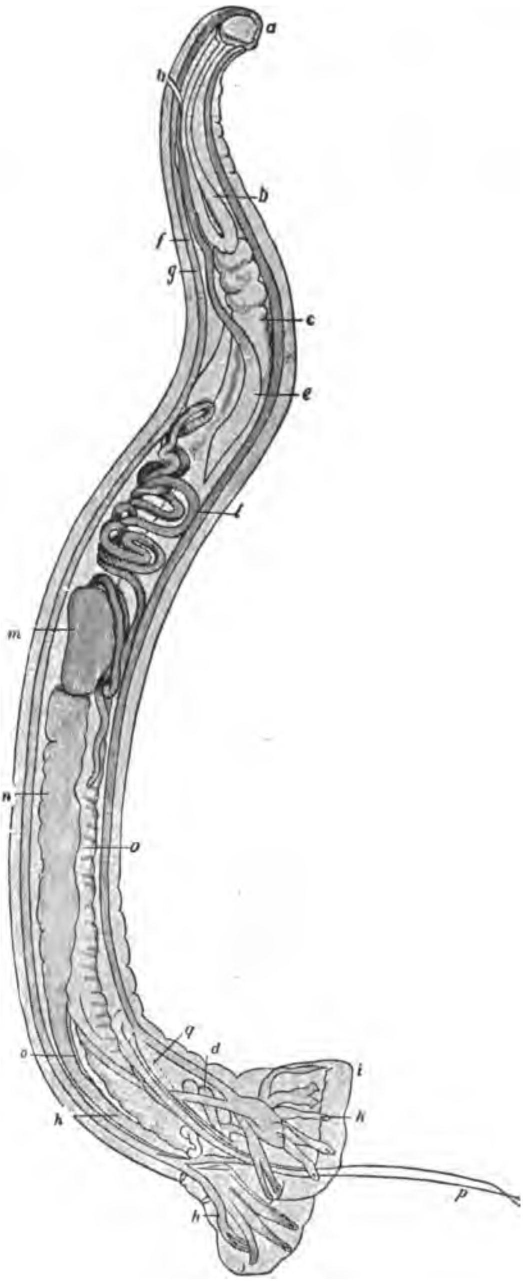


FIG. 178.—*Ascaris lumbricoides.* *A*, female; *B*, male; *C*, egg; at *a* the female genital opening; *c*, the male spicules; *b*, the enlarged cephalic extremity, with its three lips. (After Perlo, from Ziegler.)

FIG. 179.—Male of *Anchylostoma duodenale.* *a*, head; *b*, esophagus; *c*, gut; *d*, anal glands; *e*, cervical glands; *f*, skin; *g*, muscular layer; *h*, excretory pore; *i*, trilobed bursa; *k*, ribs of bursa; *l*, seminal duct; *m*, vesicula seminalis; *n*, ductus ejaculatorius; *o*, its groove; *p*, penis; *q*, penile sheath. × 20. (After Schulthess, from Ziegler.)

host. Hookworm is an ancient and world-wide disease that belts the earth in a zone about 36° north to 30° south parallel. In some parts of this district, like Samoa, 70 per cent. of the population, in southern China 75 per cent., in India from 60 to 80 per cent., in Dutch Guiana 90 per cent. are found to harbor hookworms. The economic loss from a disease so widespread is enormous. A physically sound coffee-picker in Porto Rico picks 500 to 600 measures a day; the anemic picker averages from 100 to 250 measures. The effects of this disease in stemming the progress of civilization in China India, Egypt, and other countries cannot be measured. The practical aspect of the question comes in determining the admission of immigrants from hookworm countries. In 1911 a shipload of Indian coolies landed at San Francisco and when examined 90 per cent. were found to be infected. A low class of immigrants with their lack of sanitary knowledge becomes a center from which such diseases spread. Dr. C. W. Stiles, the great authority on this disease, believes that the sanitary privy in the non-sewered districts of the Gulf-Atlantic States and the wearing of shoes are the most important measures in preventing the hookworm disease.

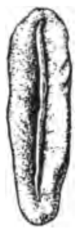


FIG. 180.—A normal-sized kidney in the frog (× 2x) showing the normal adrenal.

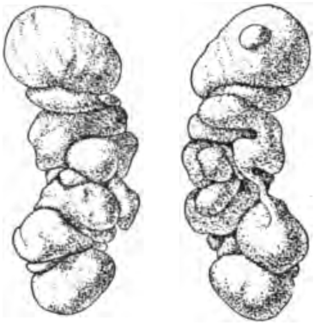


FIG. 181.—The dorsal and ventral view of the right kidney of the frog having the adrenal tumor.[1] × 2x.

Animal Tumors.—Just how the various abnormal growths so frequently found in all of the higher animals are to be explained remains to be discovered. The recent studies on crown gall suggest that the cause may be due to microörganisms which our present technic does not reveal. This suggestion has much force in it when it is remembered that there are several diseases due to the so-called filterable viruses. These tumor-like growths are found in all of the vertebrates. A characteristic instance is shown in the kidney of the frog. This organ is usually regular in outline and of a dark red color. It is about 14 mm. long and 4 mm. wide. The kidneys shown in Fig. 181 were 21 mm. long and 8 mm. wide, and irregular in outline. The color of the fresh diseased kidney was whitish. Each kidney has a large number of lobes. The tumor growth is so extensive that the original kidney is revealed only in blotches and the ureter is carried around to the inner edge instead of being on the outer edge of the kidney. The cells were in active stages of division and showed the usual atypical forms (Fig. 182). The conditions in the frog are similar to those that are often found in human adrenal tumors. It is greatly to be hoped that these strange abnormal growths in man and other vertebrates will finally be shown to be due to microörganisms, for then science can probably tell us how to prevent them.

---

[1] Adrenal Tumors in Kidney of the Frog, Anat. Auz., 1905, Bd. xxvi, No. 24.

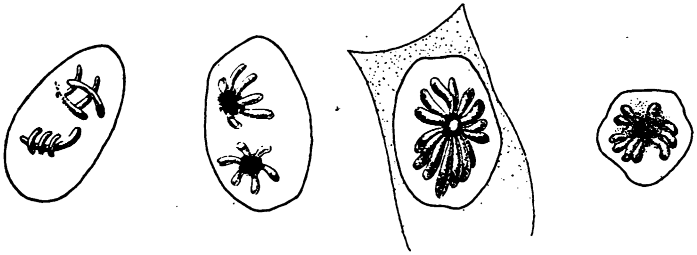


FIG. 182.—Nuclei showing atypical mitosis characteristic of the adrenal tumor in the kidney of the frog.

Disease Carriers.—The part played by biology in helping to solve the nature of disease and of the various organisms that infect the body has been great, but biologists found an equally fertile field for study in unravelling the manner in which disease was carried from the sick to the well. The recognition that definite living organisms are responsible for the transmission of disease has revolutionized the methods employed in fighting the further spread of many of the infectious diseases. *The term carrier is given to animals or persons who, apparently in good health, harbor and spread disease germs.* The fact that a man appears well and yet may be spreading disease is a new idea in preventive medicine. This in no way eliminates the old idea that contact with the sick furnishes a means of transmission of disease but rather adds another source of infection. During the convalescence of a patient it is to be expected that some germs will be found, but their persistence in a person after he is well or their existence in a person who has never had the disease is difficult to explain. Among men there are (1) convalescent, (2) chronic, and (3) healthy carriers. Diphtheria and typhoid fever are two common diseases in connection with which carriers are found. The spread of epidemics is now frequently traced to a person who believed himself to be perfectly free from such germs. The elimination of the sporadic cases of diphtheria in certain schools is now readily accomplished by simply locating the diphtheria carriers in the school. Malta fever furnishes an interesting illustration of the principles involved. This disease is due to *Micrococcus melitensis.* The goat is really a chronic carrier of these bacteria. When the goats on the Island of Malta were examined by the British Commission fully 50 per cent. gave a test which showed that they were harboring the germs and 10 per cent. were actually secreting the bacteria in their milk. All that was necessary was to boil the goat's milk or avoid using it to put a stop to Malta fever. In a similar way milk tuberculosis is caused.

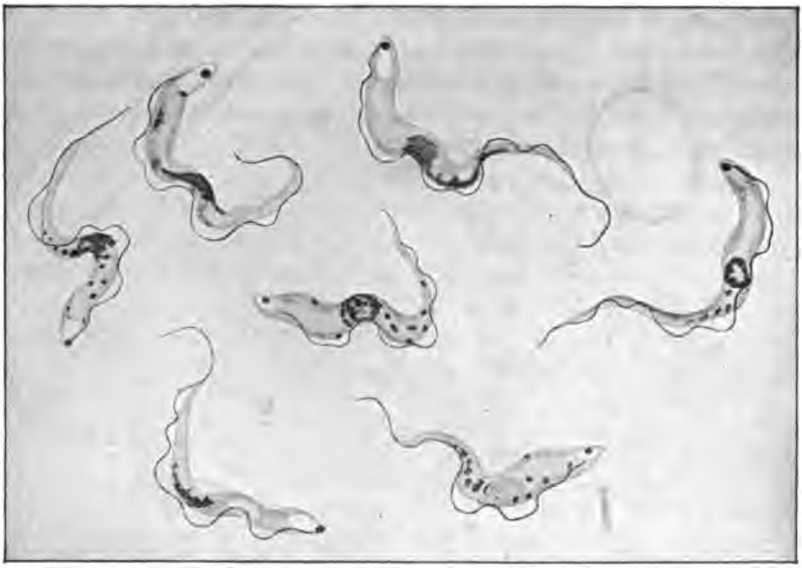


Fig. 183.—Trypanosomes (*T. gambiense*) from the blood in sleeping sickness. × 2000. (Bruce.)

The part played by animals in acting as carriers for the protozoan diseases is of great importance, for they may act as the natural reservoirs of the virus and are thus responsible for the continued existence of the disease. Among the animals that act as carriers of the protozoa the insects rank first. Their relation to the animal germs is a passive one when they accidentally convey them, and active when they are really diseased. The fly[1] feeding upon the excreta of typhoid patients may carry the typhoid germs on its body and when it alights upon food simply leave them; or the anopheles mosquito may be diseased by the malarial plasmodium and under proper conditions, on biting a person, transmit the malarial germs. The bubonic plague furnishes one of the best illustrations of the part played by insects in acting as carriers. This disease is spread by the bite of fleas which come from rats or squirrels that have been infected. The plague bacillus develops in the digestive canal of the flea and escapes with the excreta. While the flea seems to be unaffected by the presence of these germs, if the excretal matter of such fleas comes in contact with a wound, according to Hindle, the infection occurs, although it may be contracted through the salivary secretion.

The Prevention of Disease.—This is the field in which humanity can do its greatest work. The task is stupendous. The mere facts that certain diseases, like hookworm, extend in a belt around the world and among the lowest forms of civilization, that tuberculosis is killing thousands annually, that malaria and yellow fever have devastated cities, and bubonic plague unrestricted may sweep through a nation, reveal something of the scope of the problem of prevention. *All diseases which are due to the presence of some organism are preventable, and this fact alone is one to furnish all with enthusiasm for a work that must continue for many years to come.* An important incident in the United States which indicates that there is a responsibility in the matter of preventing disease is the recent decision of one of the courts in Minnesota that a city is responsible for the purity of its water supply, and that when a person contracts typhoid fever and dies, his heirs can sue the city for damages. Such a decision is an indication of progress. The world-wide dissemination of the truth about disease is an undertaking which will require years, but which must be accomplished in order to prevent the spread of plague from nation to nation.

Scientists are able to approach the problem of prevention in an intelligent manner because of the recent discoveries in regard to carriers.

---

[1] The House-fly, Musca Domestica Linn., Its Structure, Habits, Development, Relation to Disease and Control. By C. Gordon Hewitt, Cambridge University Press.

The first step in the progress of prevention is to destroy the insect carriers when practicable, or to destroy or prevent their eating in order that they may not be able to reproduce.

Human beings who act as carriers must be isolated until free from the germs or be prevented from working at trades such as dairying and cooking, which enable them to spread the germs. It is sometimes necessary to quarantine chronic carriers. The insect carriers with proper care can be prevented from biting human beings, as is illustrated by the conditions in the Panama Canal Zone which used to be like Havana, a pest-hole of disease. After a time the insect carriers should become free from disease germs, if the germs are not allowed to gain access to them. When civilization has developed to the stage that all realize that disease from parasitism is wholly preventable and that every epidemic is the result of carelessness then we may expect that sanitary precautions will be observed. After the greater part of the United States has been free from any epidemic of smallpox for some years, people grow careless and neglect to be vaccinated and it breaks out again. Eternal vigilance is going to be the price that all must pay for protection from the preventable diseases even after their prevalence has been greatly reduced from what it now is, even after the world recognizes that the problem is a work in which every nation must do its part.

Immunity.—Disease has been known from remote times and yet numerous plants, animals, and men inhabit the globe. These have survived the ravages of disease or have never succumbed to infection. It is well known that there is a natural resistance to disease which men possess unequally; some are never sick and others seem to be unable to resist any form of disease. Again our powers of resistance are higher under certain conditions than under others. This power to resist the organisms that invade our bodies is immunity, and natural immunity is the degree of immunity that each person possesses. Immunity has two aspects—resistance to the microörganisms themselves and resistance to the microbial poisons.

When microbes gain access to the body of a paramecium, for example, the paramecium treats them as it would any ingested particle of food, and if the protecting cell walls of the germs cannot be broken down, the germs are eliminated. If the microbial toxins are brought in contact with these and other ciliate protozoans, there is no appreciable effect upon the protozoa. They are able to tolerate the poisons.

It has been known for some time that these simple animals are able to adapt themselves not only to altered physical conditions but to endure the toxic action of true poisons. In studying the fundamental properties of living matter this adaptability of living protoplasm must be ranked as one of the most important.

The problem of immunity is further illustrated by the degree of tolerance which different animals have to the same poisons. It is well known that sheep are the most susceptible of the mammals to the toxin of tubercle bacilli, while the guinea-pig is not very susceptible; but the guinea-pig is very susceptible to the tubercle bacilli and the sheep is very resistant, *therefore immunity to the poisons and immunity to the germs represent two distinct conditions.* The snail (*Helix pomatia*) resists the introduction of large quantities of anthrax bacilli and they soon disappear from the blood and are found in the cells of the foot, especially those which surround the pulmonary vessels. During this taking up of the anthrax bacilli the snail remains in good health. Forty-eight hours after the injection of the bacilli these cells afforded cultures which were capable of giving fatal anthrax to mice. Ten days or more passed before the phagocytes which had engulfed the bacilli had fully digested them. If anthrax bacilli are injected into the body of the perch, numerous leukocytes accumulate around and ingest them, although the peritoneal fluid furnishes a suitable culture medium for these bacteria. These and other illustrations that might be added serve to show that many animals have a natural immunity not only to the microbial poisons but also to the microbes themselves.[1]

Given this natural immunity which is found to be generally distributed among all forms of life, how does it happen that there is any sickness? It is not easy to answer this question in a word or in an elementary course, but it may be suggested that *a sufficient number of germs within the body is necessary, and that these germs must be virulent and the host receptive.* We are unable to state just what the conditions are that make a host receptive to germs or how to eliminate the condition. We say that the non-resistant host is susceptible, the resistant immune. When the germs have gained entrance to a susceptible host does the disease begin as a result of their parasitic habit or are there other factors? The parasitic nature of disease was the early conception, but it was soon found that there were a number of conditions that mere parasitism did not explain. The disease frequently followed a course that suggested that it was similar to the fermentative action of yeast, etc., and so there arose the zymotic theory of germ disease. Later it was found that the natural living processes of the bacteria produced certain waste substances, by-products of growth which were of a poisonous character, and that some of the phases of a given disease could be induced by injecting the poison. There was thus added the toxic factor of disease. This is a most important phase of the cause of the bacterial diseases, as some of the disease bacteria show very little growth in the human body. Many writers hold that these two processes should be united and that the cause of the disease is "zymotoxic." The details of this theory as well as the details connected with recovery from disease are taken up in advanced courses. It must suffice here to mention in brief outline some of the main points.

---

[1] For the detailed study of immunity, the student is referred to Metchnikoff: Immunity in Infectious Diseases. Ehrlich: Studies on Immunity.

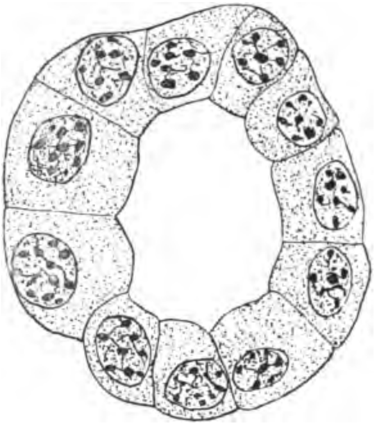


Fig. 184.—Kidney cells of normal frog. Compare these cells with those in Fig. 185.

The disease germs are destroyed by the phagocytes which ingest them and this process is fundamentally a feeding process just as is the case in the protozoa, but they are also destroyed by the juices of the body. It is believed that the body is able to secrete certain substances (antitoxins) which have the property of neutralizing the toxic products of the bacteria, and this gives the cells of the body a chance to recover. As a result of having had certain diseases one is said usually to be protected from a second attack. This is the case with most of the childhood diseases such as measles, whooping-cough, etc. When the cells of the body have become thus protected against a second attack, the term *acquired immunity* is used to distinguish it from the natural immunity which was not sufficient in such cases to prevent the disease. Acquired immunity is not a permanent condition of the cells and may disappear after one, two, three, or more years.

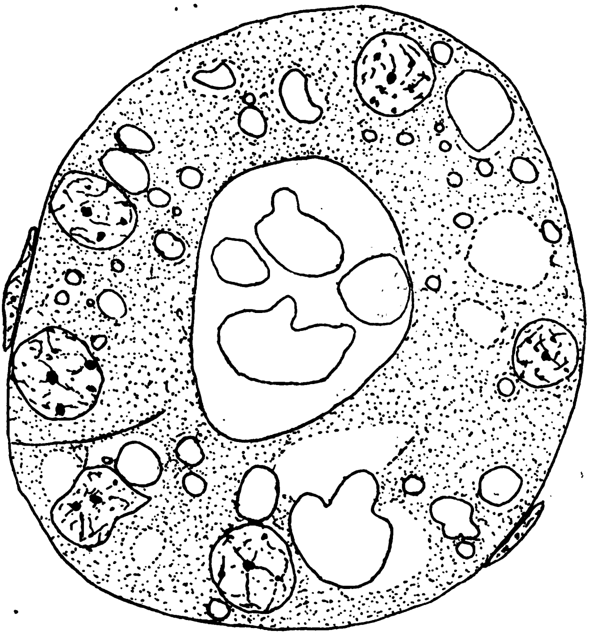


Fig. 185.—Cross-section of kidney tubule of hemorrhagic frog. The bodies with a continuous outline in the lumen and in the cytoplasm are the degenerating red blood corpuscles. This is an illustration of adaptation in the cells of the kidney to meet an emergency—the hemorrhage. (Kidney Cells of the Frog in a Phagocytic Role, Anat. Anz., 1908, Bd. xxxii, No. 8.) How do the nuclei in these cells differ from those in Fig. 184?

Protection and Adaptation.—Since Jenner, in 1798, attempted to imitate Nature and produce an immunity to certain diseases, men have been anxious to find a means of protecting their bodies from the ravages of disease. There are now some dozen or more diseases which have their antitoxin, vaccine, etc. If it were possible to remove the germs which cause disease, all of these would be unnecessary. The underlying principle in the use of these protective agents (and there must be a specific one for each disease because the toxin produced by each different germ is distinct) is gradually to accustom the cells of the body to the poison in a mild form so that during the process they will elaborate antibodies to the particular poison produced by the given organism. It is significant to note in this connection that an antibody appears in the blood whenever protein is artificially introduced into the blood. When proteins are thus injected into the blood, they act as a poison, which furnishes an artificial condition that closely approximates the toxin condition arising from bacteria. The principle thus employed is as old as the study of biology and is everywhere apparent in nature. This adaptation is one in which the living protoplasm of certain cells plays the important part. Tuberculosis may occur in the lungs; diphtheria has its location in the throat or nose; while typhoid fever is found in the blood and may be localized in the intestines, and it may be assumed that the cells which acquire an immunity to each of these diseases are not the same. In vaccination against smallpox the germs of cow-pox, a mild form of smallpox, are introduced into the body, and through the reactions of the cells of the body to the cow-pox virus the subject acquires a greater power to withstand the virulent smallpox virus.

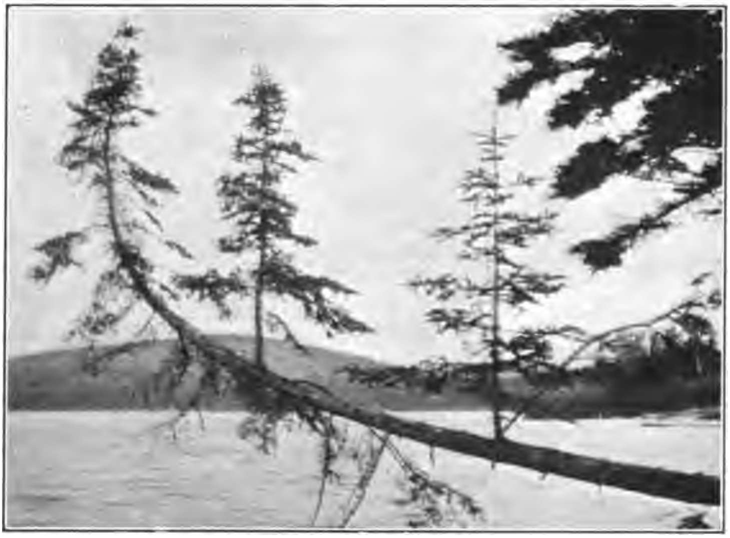


Fig. 186.—Photograph of a spruce tree which has tipped over, due to the action of the waves on the roots. The tip of the tree has adapted itself to this new position, while two of the branches have become tree-like in their symmetry and bear cones. This adaptation is especially interesting because it shows how the tree underwent a radical modification in attempting to adjust itself to its new position. The tree-like symmetry of the two limbs is a conspicuous illustration of this change.

This acquired toleration lasts through a variable number of years, but usually not more than seven. Intelligent people always keep themselves immune to smallpox, because no one can tell when or how he will be exposed. All modern nations are immunizing their soldiers against typhoid fever, and the results up to the present are very successful and are of value in civil life. The shop, the factory, the dairy, the mine, the canning industry, the meat-packing concerns, etc., all have or must adopt a new regimen as a result of the discoveries in biology during the past twenty years. State and national legislation is being enacted to compel such industries to recognize the fundamental rights of human beings to have a clean place to work, a clean place to live, and clean food to eat. The interrelation and interdependence of the human family is well illustrated in the following.

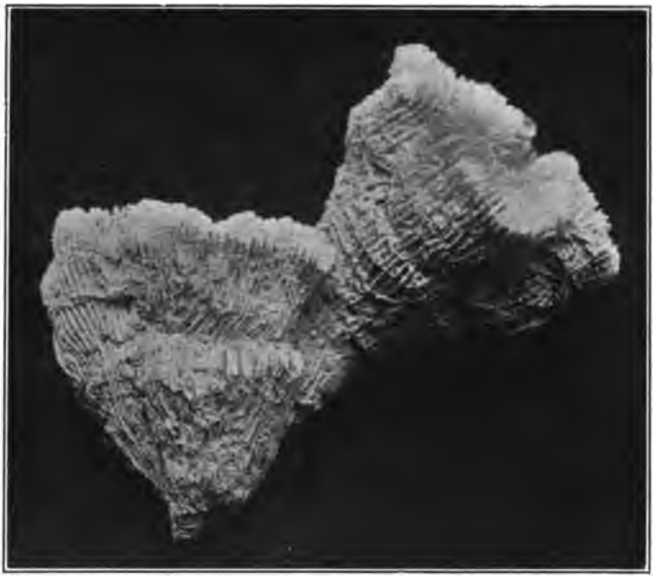


FIG. 187.—Photograph of cup coral taken at Bermuda. A heavy wind storm nearly buried in the mud the coral at the bottom and left of the figure, leaving one corner uncovered. The animal free from the mud grew up at the angle shown in the figure. The coral in adapting itself to the extremes of its environment grew in this asymmetrical manner. This figure, like Fig. 186, gives one some idea of the extent and possibilities of adaptation in nature.

The epidemic of typhoid fever and other gastro-intestinal disturbances following the Minisink banquet might be duplicated in

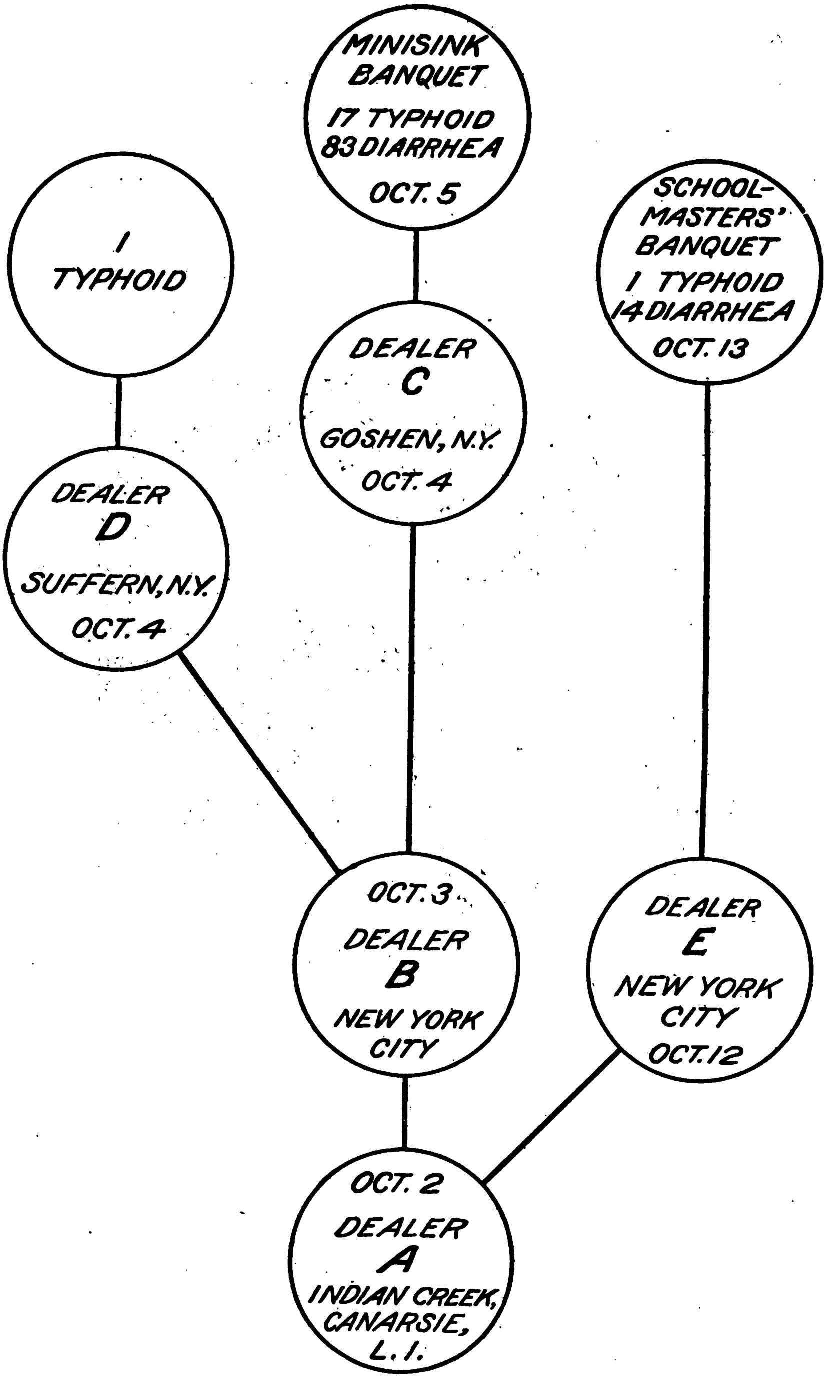


FIG. 188.—Cases of typhoid and enteritis traced back to Rockaway oysters sold by dealer *A*. (George W. Stiles.)

so far as the biological principles are involved by many examples. There were 155 guests at the Minisink banquet and within a short time afterward a large number of illnesses occurred. The graphic statement in Fig. 188 shows that nearly all were sick, and when the history of each case was known it was found that those who were sick had eaten oysters at the banquet. After a painstaking examination of the facts connected with the collection, storage, and shipment of the oysters it was proved that the bacteria in them were the cause of the illness that followed the banquet. The oysters used were collected from oyster grounds in Jamaica Bay which are polluted with sewage. They were then taken to Indian Creek near Canarsie, Long Island, and placed in the dealer's cellar, which was flooded at high tide with the water of Indian Creek. The bacteriological examination of the water and oysters collected from Jamaica Bay shows that the water was dangerously polluted. Typhoid fever bacilli were isolated from oysters as well as *Bacilli coli* and others which would give all of the germs necessary to account for the illness which followed the banquet.

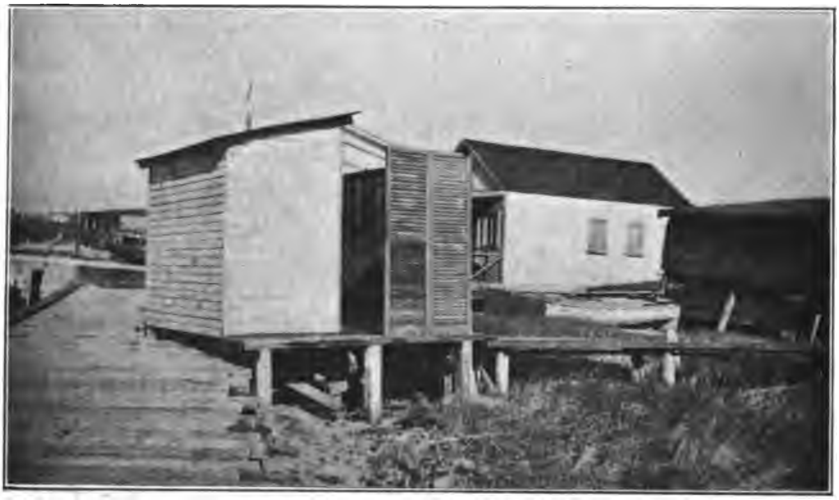


FIG. 189.—A three-compartment privy located directly over Indian Creek not far below dealer *A*. This is one of the immediate and specific sources of pollution in this creek. (George W. Stiles.)

The details of this case are given to show how much we are dependent upon others for our food and how little most of us know about the conditions which obtain in the collection and preparation of this food. The dealer who supplied these oysters was ignorant of the detailed biological information involved. Business men at the banquet were kept from their work for weeks because of his ignorance or wilful neglect of sanitary regulations. The problems of protection against disease are interwoven with many established industries which must be made to recognize the fundamental principles of disease and its spread. This will require a long period of agitation and a more perfect board of health organized as a national department and having charge over the great problems of the spread of disease. Many improvements are bound to come along this line of protection in the next few years.

CHAPTER XXII.

EVOLUTION.

As the word evolution came into early use it had reference to the manner in which organisms during growth gradually acquire adult characters. Thus the notion of an unrolling or unfolding was from the first associated with the term. Such a view assumes that certain conditions have preëxisted and that there is a direct relation between the structures that finally appear and those that give rise to them. Various other ideas were connected with the term evolution, but the most important feature of this early conception is the idea that present conditions are related to past causes. A large body of literature has grown up around this theme which has now become a household word; and, in this elementary introduction to evolution, one cannot hope to do more than to explain some of its relations to biology. An understanding of evolution involves a knowledge of heredity and variation which are discussed in the following chapter. A recent writer suggests that the word evolution is now legitimately used in four different senses. "It is the name of a branch of science; it is a theory of organic existence; it is a method of investigation, and it is the basis of a system of philosophy." (Jordan.)

Organic evolution is the name of a branch of the science of biology, and it has for its purpose the study of the relations of organisms to the unchanging laws of nature. As soon as one tries to find a leaf that is unchanging day after day, or an animal that does not vary any from week to week, he begins to realize that there is a great deal of change going on in living things. Environment is not constant and the changes in an organism are greater than most of us realize. The animal and the plant change form and grow new parts, and neither ever regains its first form. But the conditions of life, growth, and death are ever the same. In whatever place life happens to be or in whatever state, it is continually subject to the unchanging laws of nature.

Evolution is a method of study which is applicable to all forms of problems. It suggests that the present conditions of nature explain past changes and that the present is understood in the light of the past; in short, that there is a causal relation between the present and the past, whether it be in the origin of an organ or whether it be the Crusades in history. This aspect of evolution might better be designated the Scientific Method, for this method has come to have a wide application and is a better statement of this aspect of evolution. As an aid to clearness in thinking we may say that the scientific method implies the following: (1) That the happenings of today are each the outgrowth and continuation of some previous happening which it is customary to speak of as the cause and it is proper to ask in what sense it is a cause, why it is a cause and if it is the only cause; (2) that a selected cause initiates one or more happenings which are designated as effects and it is this definite relationship between cause and effect that constitutes the essence of the scientific method; (3) that progress has taken place as a result of these relationships; (4) that the living and non-living world can be classified, which has resulted in substituting order for chaos; (5) that similarities are mainly emphasized by this method of study; (6) that a given cause possesses a certain amount of energy but does not deal with original or productive causes; (7) that this method of study neither adds nor subtracts anything from the facts but is simply a method of examining the facts and classifying the happenings of nature.

Evolution is a theory of organic existence in that it seeks to explain the origin of organs, the formation of species, and the divergence between species in plants and animals. As such it will form the main part of this chapter. Beginning students should be warned that there is much that still remains unsolved in the evolutionary theory of organic existence as Jennings[1] clearly indicates in a recent address which he begins as follows: "The problem of the method of evolution is one which the biologist finds it impossible to leave alone, although the longer he works at it, the farther its solution fades into the distance."

Evolution as a philosophy is applied when discussing what various men have conceived to be the manner in which new species have come into existence, how the earth was formed, or the stars and planets were derived from the original nebulæ. This is the phase of evolution concerning which there are various views and about which there will be more views in the future.[2] The latter part of this chapter will present extracts from the philosophy of evolution as Lamarck and Darwin have expressed it.

---

[1] H. S. Jennings: Genetics—A lecture delivered before the Washington Academy of Sciences, 1917.

[2] The Present State of the Problem of Evolution, by Professor M. Caullery, Science, 1916, p. 547.

SOME EVIDENCES OF ORGANIC EVOLUTION.

Fundamental Characteristics of Living Things.—In every animal and plant studied or referred to in this course there have existed certain fundamental likenesses. (1) There are always present specific chemical substances united in such a way as to form protoplasm. No matter how highly differentiated this protoplasm becomes, whether it forms a part of the nerve cells of a genius or the roots of a tree, it is fundamentally the same in composition. (2) Metabolism is a term that includes many changes associated with the building up and tearing down processes of living protoplasm and in all life it is essentially the same, and could we explain it fully in one plant or one animal we could explain it fully in all. (3) Living protoplasm always exists in cells. Structurally the unicellular organism which retains its individuality for possibly thirty minutes can be compared with the cells found in the giant redwood tree which lives for centuries. (4) Every living thing in the world today came into existence through the direct influence of some similar form of life. This statement will remain true as a characteristic of life and as evidence of relationship in life no matter if life should arise spontaneously in the future. The important fact is that the present forms of life on the earth are genetically related. These are fundamental facts concerning which all are in agreement and they predicate distinct aspects of relationship between organic beings. The complex characteristics existing in all organisms do not rise independently with the birth of a new rose plant or new fly, but are handed down from the parent rose and the parent fly. In a similar manner these characters have been passed on to all, beginning with the simplest and gradually extending to the more complex.

Embryology.—Every living thing is capable of being analyzed into a common structure, the cell, which is the smallest biological unit in which life exists independently. The origin of new individuals in nature begins by the formation of this unit of structure. In the simpler types of life this consists in growing a cell like the parent cell; but in all the highly differentiated organisms the adult condition is reached only after a period of growth. The changes through which the frog or the chick or man passes in developing from the one-celled stage to the adult are regular and constant. The fertilized egg cell begins to segment, that is, to grow new cells, and continues until the cells become definitely arranged into layers. These cells, alike in size and kind, are first arranged in two specific layers according to their relation to the future longitudinal axis of the dorsal or median side of the adult. As soon as this disposition of the cells occurs the embryologist can locate the regions from which the adult organs are to arise, and because of this fact these two layers are known as germ layers. A little later a third germ layer is formed between the earlier two. It is important to realize the significance of these germ layers, for they are present in all of the vertebrate animals and many of the invertebrates in a similar relation both as to origin and as to subsequent history. The detailed history of the germ layers is too technical and extensive for our purpose, but we may indicate the more important results. From the outer germ layer arise the skin, the entire nervous system, and the tissue lining the anterior and posterior parts of the alimentary tract. The middle germ layer is transformed into the muscular system, blood, bloodvessels, reproductive organs, and certain outer layers of the alimentary canal; while the inner germ layer becomes the lining of the alimentary canal and gives rise to the lungs, the liver, and the pancreas. In all of these wonderful changes there are no breaks but serial transformations—the simple giving rise to the more complex—the general becoming specific, and we speak of this as a process of differentiation. Do all of the adult organs form in the most direct manner possible and is Nature economical in utilizing the most expedient measures in producing them? Let us examine one or two organs as examples.

During the early growth of the human embryo there are found in the side of the neck a number of openings (Figs. 190 and 191) which can be easily seen; these are in position and shape similar to the gill openings in the neck of the adult fish. After a time the tissues on each side of these embryonic structures are transformed into the lower jaws, the bones in the ear, and the larynx. It requires energy and time to form these useless openings in the neck and it is a circuitous method of producing the needed and necessary adult parts. The openings are known as gill-slits or gill-clefts and are likewise found in the embryo of birds, reptiles, amphibians, and fishes. A critical study of their origin indicates that they are the same in each group of animals where they exist. Nature is very extravagant in the method employed in producing some of the adult organs in man.

Intimately associated with the formation of the embryonic gill-clefts are accompanying changes in the bloodvessels just after they leave the heart, which also illustrate this same point. There is present in man one large artery leaving the heart, and from this others arise; this artery extends from the heart to the posterior regions of the abdominal cavity and is called the aortic arch in the region near

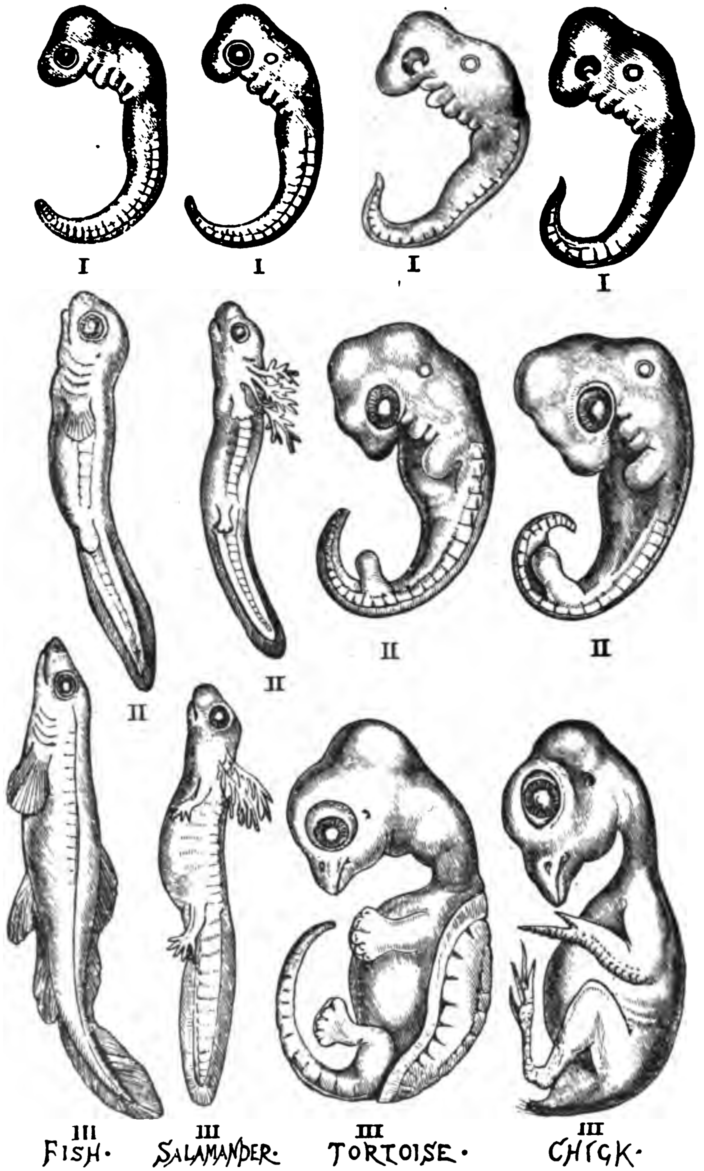


Fig. 190.—A series of embryos at three comparable and progressive stages of development (marked I, II, III), representing each of the classes of vertebrate animals below the mammalia. (After Haeckel, with permission of the Open Court Publishing Co.)

the heart because of its embryonic history; for in the embryo there are six well-defined aortic arches which pass around by the neck, hav-

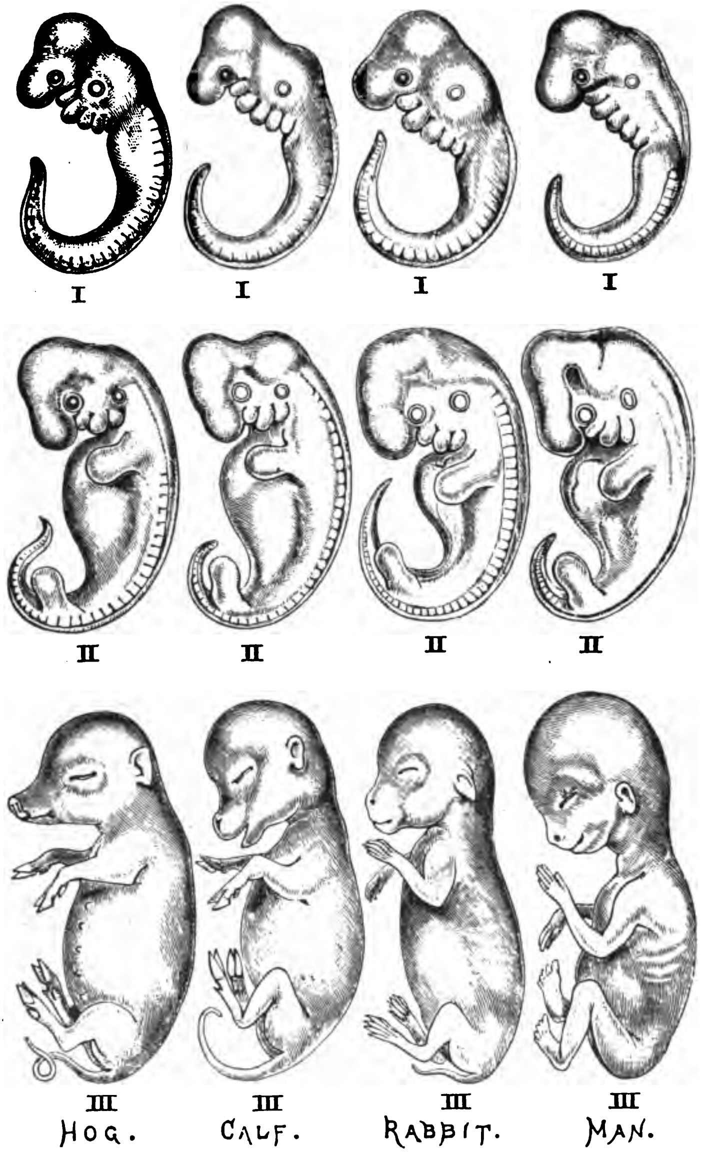


FIG. 191.—Another series of embryos, also at three comparable and progressive stages of development (marked I, II, III), representing four different divisions of the class mammalia. (After Haeckel, with permission of the Open Court Publishing Co.)

ing a gill-cleft between them. What becomes of them? Five of these embryonic arches are absorbed, one remains in the adult and we know just which one of the six branches it is and can predict with assurance that this specific branch will be the one to persist.

These illustrations are sufficient to present the next principle of development, namely, that the adult organs are products of the past, and so indelibly has the past stamped itself on the present that the growing organism cannot avoid travelling many circuitous routes before reaching its adult state. In our embryologies this principle is known as "recapitulation" and means that the adult passes in its embryology through certain ancestral stages and that from these stages some idea of its remote ancestry is obtained. This theory in various forms is part of all works on embryology; it has been attributed to several men but is found in writings that antedate Haeckel and von Baer. All of which simply means that all students of embryology, from the first observers of the developing chick down to the present time, have been profoundly impressed with this tendency of the embryo to go through many needless processes. One writer characterizes the human embryo as an "old curiosity shop" where unknown and obsolete parts, absent in the adults, are to be found. We need not concern ourselves with the shades of interpretation nor the quarrels of theorists, but with the fundamental facts that the embryo of all of the higher animals exhibits many curious structures that do not appear in the adult, and the best scientific explanation accepted today is that they are inheritances from the remote past.

The evidences which embryology furnishes of the relationship and derivation of animals or of plants is regarded as very important.

Homology.—The similar manner in which the same parts in widely different animals develop enables the expert to detect important relationships. An examination of the skeletons shown in Figs. 2 to 8 (pp. 19 to 22) indicates that the vertebral column of one contains the same kind of vertebræ as those in all the others. The bones in the arms and legs show the same fundamental number of elements, although variously modified (Fig. 192). The bones in the wing of a bird are like those in our arm, although there are more bones in our wrist, but in the embryonic wing the missing bones are present. Some adult organs thus reach their state through a growth from the simple to the complex, and later assume the simpler form. Many other common relations and organs are associated in animals that possess a backbone such as a dorsally placed nervous system containing a neurocele, a ventral cœlome containing the organs of digestion, reproduction, etc. But *no matter* how numerous these similarities are, they never amount to identity.

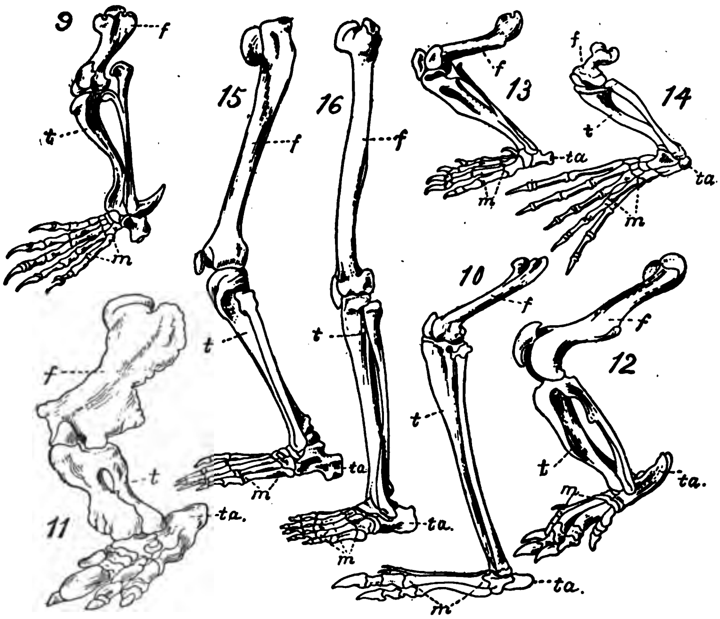


Fig. 192.—Limb skeletons of various animals, showing homologous bones: *9*, ornithorhynchus; *10*, kangaroo; *11*, megatherium; *12*, armadillo; *13*, mole; *14*, sea lion; *15*, gorilla; *16*, man. (From Jordan and Kellog.)

No matter how different the general appearance of organs or structures, and no matter how different their general function, if they can be shown to have had a common origin, they are said to be homologous. Homologous organs usually have the same relative position on the animal. This means that organic beings are constructed of corresponding parts, and that the only difference between them consists in variations in the original and fixed number of elements. An element may be large in one animal and small in another; simple or complex, as in appendages of crayfish (Fig. 142).

The chief difference in the group of vertebrate animals consists in variations in the number of fixed elements that constitute the typical vertebrate. This study of homology serves to show the relationships in similar and also in some divergent adult morphological structures. The manner in which the differences in these homologous organs have been brought about in Nature belongs to the philosophic phase of evolution, but all are agreed concerning the facts of homology and the relationship thus indicated.

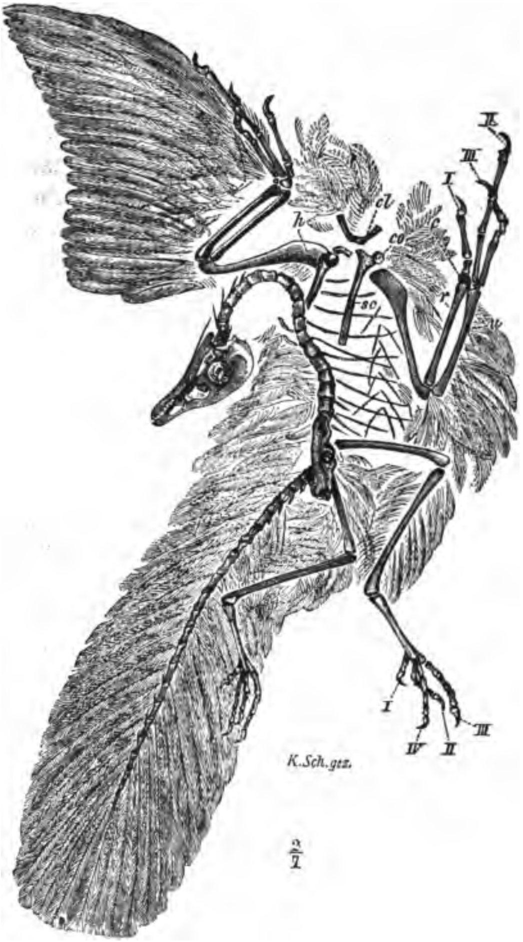


FIG. 193.—*Archæopteryx lithographica.* (After Dames, from Wiederscheim.)

Palæontology.—From the time scientists first began to try to understand the formation of the earth up to the present they have been impressed with the story that is told by the record of the rocks and their fossils. But there are many blank pages and often whole chapters missing whose absence perplexes and disappoints us. A fossil is defined as any part of an organic body that has become definitely preserved in the rocks; a tooth, a feather, or a footprint each tells a truthful story. The fossils show many transitional types of animals between the great groups such as the archæopteryx, part bird and part reptile (Fig. 193). Geology also indicates that all of the great groups of animals were in existence before the age of man, but the beginning of many classes is missing either because no record was preserved in the rocks or else because it has not yet been found. The ancient animals and plants lived and struggled and were parasitized just as organisms live and struggle and are parasitized today; they came into existence in the same way and show the same relationships. Many of the modern phyla would be isolated and aberrant were it not for the fossils which serve to show their connections with well-established groups.

PHILOSOPHY OF ORGANIC EVOLUTION.

The several ways in which these facts have been interpreted constitute the philosophy of evolution. Among the men whose names rank foremost in presenting a consistent theory of organic evolution, those of Lamarck and Darwin stand foremost. However, all writers on the philosophy of evolution divide their subject into (1) heredity, (2) variation, and (3) prodigality of Nature, as living matter is continually subject to all three of these conditions. By heredity is meant the tendency which every animal or plant has to perpetuate itself in its offspring. The wolf never begets a dog nor does the rose bush bear lily blossoms; nor can man by all of his skill set aside this tendency; it is as fixed as the law of gravitation. But the similarity never amounts to identity; the offspring exhibit a given amount of difference, small in some instances large in others. These differences are called variations and are of great importance. Were there no variations, there would be no progress: our trees, fruits, horses, cows, etc., of today would be the same as the first tree, the first fruit, the first horse, the first cow, and it would be impossible to improve or change the type.

The prodigality of Nature has to do with the enormous reproductive possibilities of plants and animals. The unobservant rarely stop to consider that in the keen contest for food and a place to live animals and plants are in competition especially with those forms with which they are closely akin. The dream of those who long for a life as free as the bird that darts through the air or the fish that glides through the water is not founded on fact. Every living thing has to participate in a contest for its existence more or less severe, because of the limited amount of food and space. Unhindered plants and animals reproduce in geometrical ratio. This latter fact may need illustrating. Robin redbreast raises annually one or two broods which should result in an average of four young. The following table from Metcalf shows the result for ten years at a similar rate of increase:

	Adult.	Young.
One pair of adult robins	2	4
Second year	6	12
Third year	18	36
Fourth year	54	108
Fifth year	162	324
Sixth year	486	972
Seventh year	1,478	2,916
Eighth year	4,374	8,748
Ninth year	13,122	26,244
Tenth year	39,366	78,732
End of tenth year	118,095	

If even this low estimate should obtain, there would not be enough robin food in the world for them to live on. Among the fishes the possibility for increase is multiplied many fold; some single fish annually lay several million eggs and the young become sexually mature in two or three years. The insects furnish additional facts: a single flesh-eating fly (*Musca carnaria*) produces 20,000 larvæ, and these grow so quickly that they reach their full size in five days. The great Swedish naturalist Linnæus asserted that a dead horse could be devoured by three of these flies as quickly as by a lion. Each of these larvæ remains in the pupa stage about five or six days, so that each parent fly may be increased two thousandfold in a fortnight.

Enormous possibilities of increase are found in nearly all of the simpler animals, and the figures for plants are of a similar nature, but the more interesting fact is that the number of robins, or flies, is not on the increase from year to year—what must then be the death-rate for these rapidly increasing organisms? Our authority says: "Taking animals as a whole, it would be safe to say that hundreds of thousands die every year for each one that lives." What holds the animals and plants in check when they are all potentially capable of becoming much more numerous? Starvation, heat and cold, floods, droughts, storms, carnivorous and herbivorous enemies, diseases, etc. Each claims its share. "Nature is fertile in expedients for killing. Life is not easy. Those that live pass through a severe test with the result that only those best fitted for the contest survive —the weaklings have small chance of reaching maturity. In a struggle so severe, any advantage, however slight, of greater vigor or better structure, may be decisive and turn the scale." (Metcalf.)

Fig. 194.—Lamarck (1744–1829). (From Locy's Biology and Its Makers.)

The philosophy of evolution takes these three tools: heredity, variation, and the prodigality of Nature, and tries to form an explanation of the series of progressive changes that have taken place in animals and plants. These are the main lines of study, and various theories have been grouped about one or the other or all three.

Thus far in this discussion all easily agree, but when it comes to applying the theories to these three phases of evolution there are many opinions. Some men of large vision accompanied by a deep study of many facts have given us their explanation. The limits of this chapter forbid extensive review of even two or three of the most prominent writers. Under various guises several of the fundamental features of evolution are found in the writings of men from Aristotle down to Erasmus Darwin (1731–1802), who was a firm believer in evolution.

Lamarck's (1744–1829) life is the old, old story of a man of genius who lived far in advance of his age, and who died comparatively unappreciated and neglected. In the history of the development of the idea of evolution he is the most prominent figure between Aristotle and Charles Darwin. His treatise *Philosophie Zoölogique* shows "first, the certainty that species vary under changing external influences; second, that there is a fundamental unity in the animal kingdom; third, that there is a progressive and perfecting development." To Lamarck is given the credit for having been the first to formulate a definite theory of evolution.

Lamarck is chiefly known for the four laws of evolution which Osborne translates as follows: (1) The Law of Growth. Life by its internal forces tends continuously to increase the volume of everybody that possesses it, as well as to increase the size of all the parts of the body up to a limit which it brings about. (2) The Law of Functional Reaction. The production of a new organ or part results from a new need or want, which continues to be felt, and from the new movement which the need initiates and continues. (3) The well-known Law of Use and Disuse. The development of organs and their force or power of action are always in direct relation to the employment of these organs. (4) Use Inheritance. All that has been acquired or altered in the organization of the individuals during their life is preserved by generations and transmitted to new individuals which proceed from those which have undergone these changes. Lamarck, like Erasmus Darwin, accepted spontaneous generation, for he held that Nature was always creating elemental plants and animals.

Charles Robert Darwin (1809–1882), the great naturalist and author, by his interpretation as a result of his study, made a most notable contribution to our conception of evolution.

From 1831 to 1836 he acted as naturalist on H. M. S. *Beagle*, which made an extensive surveying expedition. During this time he thought and read about the collections of fossil and living forms made by the *Beagle,* and he says that it was "by far the most important event in my life, and has determined my whole career." On his

FIG. 195.—Charles Robert Darwin (1809–1882). (From Locy's Biology and Its Makers.)

return, he published his observations in *A Naturalist's Voyage,* which is one of the most delightful records of a naturalist's travels ever produced.

Darwin owed a great deal to his predecessors, more than is generally believed, because a rather complete conception of evolution had already been reached, and some of the evidence stated. He was strongly influenced by reading Lyell's *Principles of Geology*, and later while studying domestic animals he read Malthus *On Population*, as a result of which "the idea of selection in a state of nature first occurred to him as a result of the struggle for existence, or rather for life, between different individuals and species." Darwin's great contribution to evolution is the *Origin of Species* as a result of a struggle, utilizing variations and letting nature select, which is what is meant by the term "Natural Selection" or the "Survival of the Fittest." "Natural selection, then, is a theory which seeks to explain by natural causes the occurrence of every kind of adaptation which is to be met with in organic nature, on the assumption that adaptations of every kind have primary reference to the preservation of species, and therefore also, as a general rule, to the preservation of their constituent individuals."

Variation, then, is the keynote to Darwinism, and one of the chief lines of research since his time has been the attempt to determine the causes of variation. Some idea of Darwin's notion in regard to variation is to be gained from the following: "It seems clear that organic beings must be exposed during several generations to new conditions to cause any great amount of variation, and that when the organism has once begun to vary, it generally continues varying for many generations. No case is on record of a variable organism ceasing to vary under cultivation. Our oldest cultivated plants, such as wheat, still yield new varieties; our oldest domesticated animals are still capable of rapid improvement or modification."

During the time of Lamarck and Darwin the opinion was very general that species were immutable and remained so unless changed by a distinct creation. Today it is regarded as a difficult problem to formulate a satisfactory definition of species. Darwin maintained that varieties arise through individual differences. "Hence I look at individual differences, though of small interest to the systematist, as of the highest importance to us, as being the first steps toward slight varieties as are hardly worth recording in natural history. And I look at varieties which are in any degree more strongly marked and permanent, as steps toward more strongly marked and permanent varieties; and at the latter as leading to subspecies. . . . Again it may be asked, How is it that varieties which I have called incipient species become ultimately converted into good and distinct species, which in most cases obviously differ from each other far more than do the varieties of the same species? How do these groups of species, which constitute what are called distinct genera, and which differ from each other more than do the species of the same genus, arise? All of these results follow from the struggle for life. Owing to this struggle, variations, however slight and from whatever cause proceeding, if they be in any degree profitable to the individuals of a species in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be transmitted to the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection, in order to mark its relation to man's power of selection. But the expression often used by Mr. Herbert Spencer of the Survival of the Fittest is more accurate and is sometimes equally convenient. We have seen that man by selection can certainly produce great results, and can adapt organic beings to his own uses, through the accumulations of slight but useful variations, given to him by the hand of Nature. But natural selection, as we shall hereafter see, is a power incessantly ready for action, and is as immeasurably superior to man's feeble efforts as the works of nature are to those of art."

There has been considerable hysterical writing in regard to the brutality of the struggle for existence which has been read into and superimposed on Darwin's original conception. "I (Darwin) should premise that I use this term in a larger and metamorphical sense, including dependence of one being on another, and including (which is more important) not only the life of the individual, but success in leaving progeny. Two canine animals, in time of dearth, may be truly said to struggle with each other which shall get food and live. But a plant in the edge of a desert is said to struggle for life against the drought, though more properly it should be said to be dependent on moisture. A plant which actually produces a thousand seeds of which only one can manage to come to maturity may truly be said to struggle with the plants of the same and other kinds which already clothe the ground. The mistletoe is dependent on the apple, and a few other trees, but can only in a far-fetched sense be said to struggle with these trees, for if too many of these parasites grow on the same tree, it languishes and dies. But several seedling mistletoes, growing close together in the same branch, may more truly be said to struggle with each other. As the mistletoe is disseminated by birds, its existence depends on them, and it may metaphorically be said to struggle with other fruit-bearing plants, in tempting the birds to devour and thus disseminate its seeds. In these several senses, which pass into each other, I use for convenience's sake, the general term 'Struggle for Existence.' "

In these extracts in Darwin's own words, we have his methods of interpreting changes in living things. Though he was one of the most abused men of the past century, he lived to see many turn to his views. At the close of the century *The Outlook* held a contest as to the greatest book written from 1800 to 1900 and Darwin's *Origin of Species* received the largest number of votes as being the book that has had the greatest influence in molding the thought of the century.

The original conceptions of Lamarck and Darwin have been variously modified with the progress of science and new schools of neo-Lamarckians and neo-Darwinians have arisen, each holding in a modified form the original hypothesis of Lamarck and Darwin. There are other theories of evolution and it will be strange if more are not formulated in the future. Living protoplasm is so variable, plastic and adaptive that it is difficult to formulate a theory that explains all the conditions. Possibly, if the theory did explain all of the conditions, it would be as Jordan suggests, no longer philosophy, but science. *Each student should select one or two of the great books on evolution and read them in connection with this course, for the value of such books is greatly enhanced by a fresh and intimate knowledge of biological facts.*

CHAPTER XXIII.

VARIATION—HEREDITY.

VARIATION.

Definition.[1]—Variation is used in Biology to describe the differences, structural and physiological, that are always found between offspring and parents. Bateson's comprehensive definition reveals the scope of this topic. "For though on the whole the offspring is like the parent or parents, its form is perhaps never identical with theirs but generally differs from it perceptibly and sometimes materially. To this phenomenon, namely, the occurrence of differences between the structures, the instinct, or other elements which compose the mechanism of the offspring, and those which were proper to the parent, the name variation has been given."

The following brief review of some common variations aims to establish (1) the fact of variation, and (2) the extent with some reference to the kinds.

Variation in Paramecia.—Variations in protozoa have received considerable attention within the past ten years. Here a generation is produced in a day, and unlimited numbers of pedigreed stock can be secured for study in a short time. These unicellular organisms have been characterized as essentially free germ cells upon which the environment is directly acting. Jennings finds that paramecia and other protozoa are made up of numerous races, differing minutely but constantly. "The individuals of any race vary much among themselves, but these differences are matters of growth and environment, and are not inherited. What is produced in reproduction depends on the fundamental constitution of the race, not on the peculiarities of the individual parent. The fundamental constitution of the race is resistant to all sorts of influences; it changes only in excessively rare instances, and for unknown cause. In a study of thousands of individuals of paramecium, through hundreds of generations, hardly a single case of such change was observed. Most differences between individuals are purely temporary and without significance in inheritance; the others are permanent diversities between constant races. Systematic and continued selection is without effect in a pure race, and in a mixture of races its effect consists in isolating the existing races, not in producing anything new." (Jennings.)

---

[1] The several illustrations in this chapter should be thoroughly studied, for they present many important facts about the modern theory of heredity.

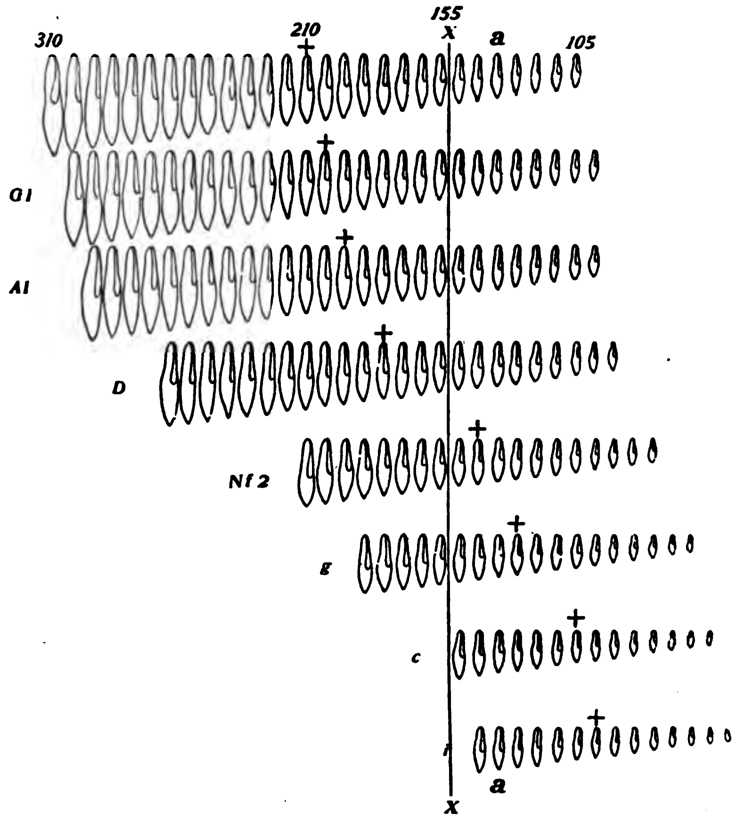


Fig. 196.—Diagram of the species of *paramecium*, as made up of eight different races. Each horizontal row represents a single race. The individual showing the mean size in each race is indicated by a cross placed above it. The mean of the entire lot is shown at *x*, *x*. The numbers show the measurements in microns. The magnification is about 43 diameters. (Jennings.)

Variation in Earthworms.—Pearl has studied 487 earthworms and finds that the range of somites is from 79 to 174, with an average of 142.71 somites, the percentage of variation being 8.31 per cent. The total length of the body ranges from 11.25 to 28.75 cm., giving a percentage of variation of 16.05 per cent. The length of the earthworm does not depend on the number of somites. In 495 individuals the number of somites anterior to the clitellum ranged from 29 to 32, or 1.41 per cent. variation. The number of somites in the clitellum was from 6 to 8, or 8.02 per cent. variation. With an increase in the number of somites in front of the clitellum, there is a marked tendency for the number in the clitellum to decrease.

Variation in Crayfish.—Variations in the crayfish have been extensively studied by Pearl, who made measurements of the length and breadth of the cephalothorax and of the several joints in the walking appendages. The cephalothorax from the tip of the rostrum to the posterior margin on the dorsal median line ranged from 19.2 mm. to 27.2 mm. in the 283 individuals measured. The head breadth ranged from 6.3 mm. to 15.3 mm. There were 50 of the 283 individuals that had a cephalothorax 24.7 mm. long: and 58 individuals that had a head breadth of an average of 10.7 mm.

The length of the three distal joints of the first three legs (cheliped and the first two walking legs) was measured. The length of the big claw-joint ranged from 12.1 mm. to 34.1 mm., with 37 individuals averaging 19.6 mm.

The joint next to this one varied from 4.7 mm. to 11.5 mm., with 49 individuals averaging 6.95 mm.

The third joint from the end varied 6.9 mm. to 14.9 mm., with 55 individuals averaging 9.65 mm.

The first walking leg compared with this claw gives the following data: Distal joint, 4.9 mm. to 10.3 mm., with 46 individuals averaging 6.95; second joint, 3.4 mm. to 7.2 mm., with 40 individuals averaging 4.9 mm.; third joint, 5.5. mm. to 11.5 mm., with 49 individuals averaging 7.7 mm.

Sufficient of Pearl's results are given to indicate a considerable range of variation. In the discussion of the paper some of the following important conclusions are formulated:

1. A relatively high degree of morphological differentiation and specialization has associated with it a relatively high degree of variability in the parts concerned.

2. There is no reasonable doubt that the differentiated specialized condition of the leg bearing the great chela is phylogenetically a relatively late acquisition. In other words, it is not a primitive morphological condition. But we find that this part which has been modified most recently phylogenetically is also the most variable of the three appendages studied.

3. The correlation between the homologous segments of the two legs is higher when these two legs belong to contiguous metameres than when they are separated by an intervening metamere.

In all of these illustrations there is (1) a large amount of variation; (2) the variation is continuous and moves in both directions from the normal, *i. e.*, the normal length of the big claw is 14.6 mm., but there are a number of individuals with longer and shorter claws.

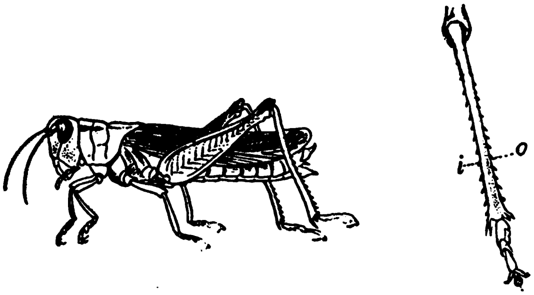


FIG. 197.—The red-legged locust. *Melanoplus femur-rubrum*, and enlarged hind tibia, showing inner (*i*) and outer (*o*) rows of spines. (Kellogg and Bell.)

The grasshopper bears on the tibia of the jumping leg two rows of spines (Fig. 197), known as the outer and inner rows. These spines vary in number in both sexes and yet the extent of the variation is constant for each species which thus affords a distinguishing character in classification.

In a study of variation some such definite structures as spines are selected which can be measured or counted, and manifestly there are many of these in most organisms. Such parts are technically called "characters." The number of tibial spines, the length of the body, and the color markings of the grasshopper are all characters. In a similar way one can select characters in plants such as the number of petals, length of petiole, or subdivisions of the leaf.

Kellogg and Bell[1] collected several lots of grasshoppers and examined the extent of the variation in the tibial spines. In lot 1 there were 39 individuals which had from 9 to 15 tibial spines. Most of the grasshoppers had 12 spines. In order to express graphically the kind and extent of variation, the results are arranged in the form of a curve (Fig. 198). The term classes indicates the form that the variation takes, *i. e.*, the tibial spines number 9, 10, 11, 12, etc. The variates are the number of individuals that have 9, 10, 11, 12, etc., tibial spines.

---

[1] Kellogg and Bell: Studies of variation in Insects, Proc. Washington Acad. Sci., December 14, 1904, vi, 203-332.

By plotting the results and giving to each variate a definite value and then connecting the several points, a line such as is illustrated in Fig. 198 results. This line is called a frequency polygon or variation curve. In this curve there is one class that has more variates than any other and for this reason is called the mode or mean class. By means of a mathematical formula the exact mean is established and the exact degree of variation from the mean determined.

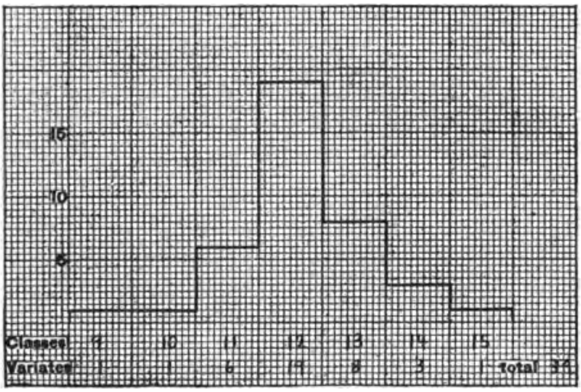


Fig. 198.—Frequency polygon of the variation in number of spines in the outer row of the right tibiæ in 39 male red-legged locusts, *Melanoplus femur-rubrum*. (Kellogg and Bell.)

In the frequency polygon in Fig. 198 it is apparent that the range of the number of spines is greater above the mean than below, which indicates the course of evolutionary movement. These studies can easily be duplicated and plotted in a similar manner while studying the grasshopper in the laboratory.

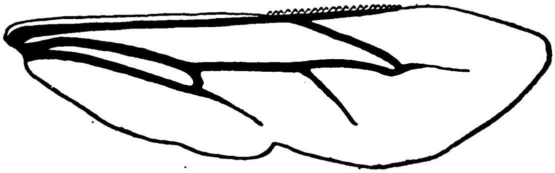


Fig. 199.—Hind wing of honey bee to show position of hooks. (Casteel and Phillips.)

Variation in Insects.—This class of animals has been extensively studied. The method and results of these studies are illustrated by the following: On the second pair of wings of the worker and drone honey bee are found a number of hooks (Figs. 199 and 200). A study of the hooks in six selected lots of drones and three lots of workers is shown in the following table. The number of hooks is shown at the top and the number of individuals at the bottom (Casteel and Phillips).

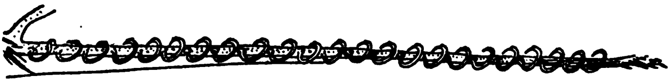


Fig. 200.—Part of the costal margin of hind wing of honey bee much magnified to show hooks. (Kellogg and Bell.)

HOOKS ON HIND WING.

Drones.

Classes.	12	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Average.
I......				4	4	8	11	9	4	6	1	1	2			21.56
II......		2	1	12	21	23	20	17	2	2						20.12
III......				1	7	12	15	28	14	14	6	2	1			22.09
IV......			4	10	17	22	27	12	2	5	1					20.33
V......				4	2	11	10	9	7	1	4	1		1		21.54
VI......	1			3	3	7	6	23	23	19	6	6	1		1	22.42
Variates	1	2	5	34	54	83	89	98	52	47	18	10	4	1	1	

Workers.

Classes.	12	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Average.
I......					6	9	12	11	6	5	1					21.42
II......			4	13	42	74	94	61	45	11	4	2				21.08
III......			2	11	18	18	33	8	6	4						20.37
Variates			6	24	66	101	139	80	57	20	5	2				

Variation in Ranunculus.—A study of 337 plants of *Ranunculus bulbosus* which normally has 5 petals gives the following:

Classes 5— 6—7—8—9, number of petals.
Variates 312—17—4—2—2, number of plants.

Here the variation is in the direction that tends to increase the number of petals.

Methods of Studying Variation.—The accurate study of variation, then, selects a character which can be accurately measured or counted; and the result of such a computation for a large number of individuals is graphically represented in a table or curve. These curves serve at a glance to indicate the extent of the variation, whether it is continuous or discontinuous, and the direction in which the variation is moving. Different values are worked out by using certain mathematical formulæ which is an attempt to express accurately the extent and significance of variation. This method has given rise to the "biometrician" school whose exact work has done much to clear up the indefiniteness of biological description. There are many biologists, however, who hold that living protoplasm cannot be measured in millimeters, and that a measurement only partly describes. Much skill is required in selecting the so-called characters in the study of variation. At present there is a vast amount of data that has been collected in variation that helps to a better understanding of living protoplasm, because this method of study emphasizes many facts that were previously overlooked.

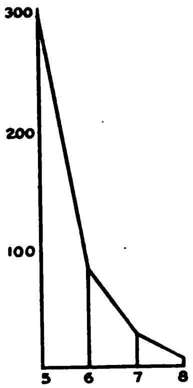


FIG. 201.—"Half-curve" representing the number of "petals" on 416 flowers of the marsh marigold (*Caltha palustris*). (From Doncaster, after De Vries.)

HEREDITY.

Heredity is the name for one aspect of protoplasmic activity. As has already been pointed out, one should know as much as possible of the structural conditions and physiological activities. Now we attempt to learn something of the history or inheritance of protoplasm, and we shall see that protoplasm is more than so many chemical elements with a certain physical appearance, it is a part of the past influencing the activities of the present.

Heredity is thus a general term in biology which is used to describe the repetition of parental characters in offspring, and so it is customary to say that the child inherits from its parents or that it has such and such a parental inheritance. The same terms are used in the transmission of property from parent to child, but there is this distinction, that the property is the same in each instance while the biological inheritance is a figure of speech. All of the parental characters are never fully reproduced in the offspring, and this fact causes many of the variations described above.

Scientists are aiming to discover the method by means of which the parental characters are made to reappear in the offspring. The investigations of this problem fall into, first, those who believe that the secret will be discovered in a study of variations; and second, those who seek it in the detailed relations that exist between the chromosomes in fertilization.

Heredity is everywhere present in organic life and serves to transmit not only useful likenesses but many that never mature or are rudimentary. The great comparative anatomist, Wiedersheim, has found 180 vestigial organs in man alone. No system of organs is free from them; the skeleton, the muscles, the nervous and digestive systems all have structures that are important to some of the lower vertebrates. The vestigial structures serve to illustrate the hold that heredity seems to have on living matter. Someone has characterized heredity as "organic memory," but this is only suggestive, for mammalian organisms are reproducing with remarkable fidelity ancient ancestral structures of the Devonian geological period which extends back in time beyond the reckoning of man. The formation of an embryonic notochord and of gill-slits illustrates this point. Heredity can thus be relied upon to produce ancestral structures both good and bad, a fact of organic life always to be reckoned with. In this general sense the main hereditary picture of most living things has been fixed for thousands of years. The modern study of heredity, however, is mainly confined to the smaller changes described as Variations, page 256.

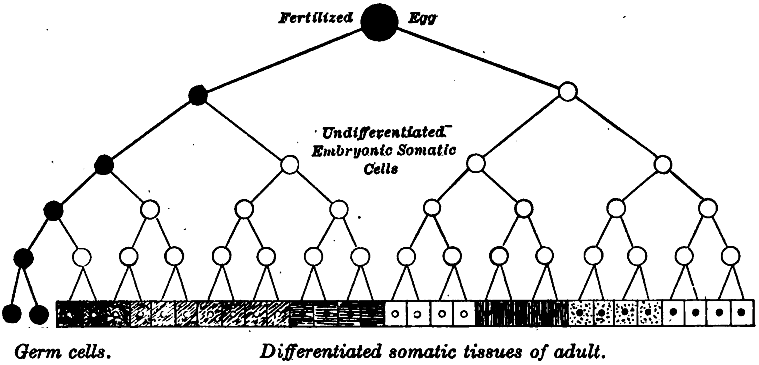

Fertilized Egg
Undifferentiated Embryonic Somatic Cells
Germ cells.
Differentiated somatic tissues of adult.

FIG. 202.—Schema of germ and somatic cell differentiation. (After Klebs.)

Heredity and the Cell.—Whatever may be the ultimate analysis of the problem of heredity, there need be no hesitation in stating that the transmitted characters exist potentially in the protoplasm of the cell. From the egg of a robin only a robin will develop, from the ovum of an oak only an oak will grow, and during growth each follows its own successive embryological stages even to the minutest details. It has been well said "Nature never yet made two eggs or two sperms exactly alike." The cells which give rise to new organisms are the germ cells, sperms, and ova.[1] These differ greatly in shape and size. It has been estimated that the volume of the human sperm is not over 50 cubic micra, while that of the human ovum is 1,767,150 cubic micra or over 35,000 times the volume of the sperm cell. The difference in volume between the sperm and ovum of the frog is more than 6 times as much as in man. But notwithstanding this disparity between male and female germ cells, it is well known that the paternal and maternal characters are about equally distributed in any population as a whole.

As has already been explained (pages 73 and 265) the egg cell passes through a period of preparation for fertilization which is known as maturation. During these changes the chromatin undergoes a rearrangement which results in both a qualitative and quantitative elimination of chromatin.

This is a complicated process which is diagrammatically illustrated in Fig. 203. The circles are the nuclei of the cells. Each contains four chromosomes which is the exact number in the parasitic threadworm, Ascaris. The primordial germ cells divide many times in a regular manner and distribute the chromatin in equal amounts to the forming cells. This stage is termed the oögonia in the case of the cells that mature into ova; and spermatogonia in the cells that are to become sperms. After a time this stage is followed by one in which the chromosomes fuse in pairs to split later longitudinally, and this stage of growth is termed the oöcyte or spermatocyte of the first order respectively. There is no division of the cytoplasm accompanying this growth change. Now the germ cells pass through a period of maturation. The ovum forms a polar cell that contains one-half of each of the four chromosomes which have divided transversely. This polar cell later divides. The egg chromosomes do not form into a nucleus following the formation of the first polar cell, but immediately separate into two groups, one-half of the number of chromosomes remaining in the ovum, one-half passing into the second polar cell. In this last change there is a qualitative separation of the chromosomes because two whole chromosomes pass out into a polar cell.

---

[1] The Basis of Individuality in Organisms from the Stand-point of Cytology and Embryology. By Professor Edwin G. Conklin, Science, 1916, p. 523.

The changes in the chromosomes in the spermatocyte are similar except that each of the four cells resulting from maturation gives rise to mature sperms; while in the ovum the three polar cells degenerate.

In the germ cells of most animals, the number of chromosomes is many more than the four found in Ascaris, but the principle does not change with this increase in number.

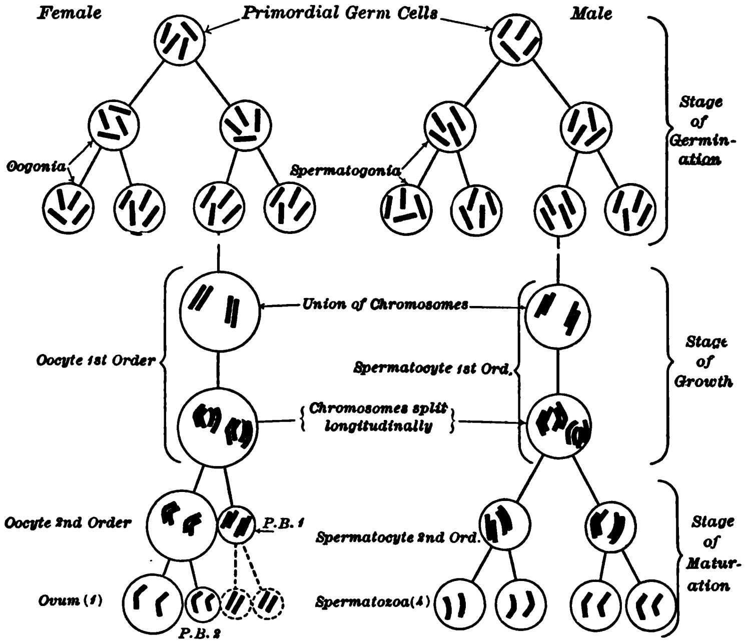


Fig. 203

The ovum and sperm are now said to be mature. Before maturation the ovum cannot be fertilized, although the sperm may enter the cytoplasm. After the sperm head enters the ovum it is transformed gradually into a nucleus containing two chromosomes (Plate I, *6*), and is now designated as the male pronucleus; while the egg nucleus is termed the female pronucleus. As each of these two pronuclei contains two chromosomes, there are now four in the ovum, which is the normal number of Ascaris, but each two chromosomes are contained in a nucleus. In order that fertilization may take place, the nuclear wall must break down and thus allow the two sets of chromosomes to come together.

Fertilization is the union of the male chromatin (chromosomes) and the female chromatin, but it is readily understood that the repeating of this process generation after generation would serve to accumulate not only a large amount but a vast number of individual chromosomes were it not for this preparatory reduction in maturation. The number of chromosomes in the developing cells of an organism is therefore the same as those of each parent and not double the number.

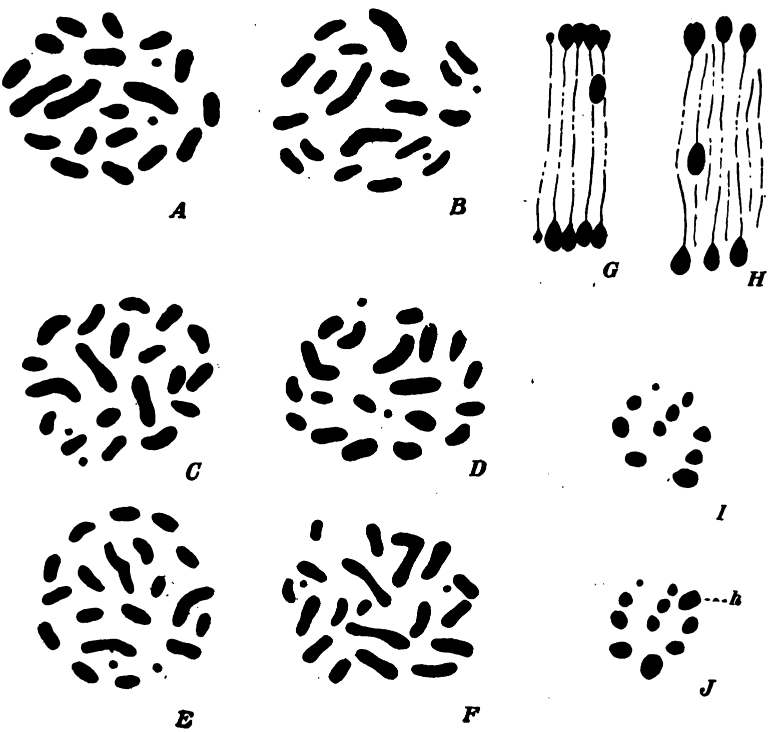


FIG. 204.—Figure to show variation in shape and size of the chromosomes. *Anasa tristis*. *A* to *F*, spermatogonial groups; *G*, *H*, anaphases of second division, showing division of *m*-chromosomes in *G*, and the undivided heterotropic chromosome on both spindles; *I*, *J*, anaphase groups from the same spindle, polar view, second division, showing *m*-chromosome and macrochromosome in each and the heterotropic (*h*) in *J*. While each species has a given number of chromosomes, they are not identical in shape and size. (After Le Fevre and McGill, in Biological Bulletin.)

The number of chromosomes or even the particles of chromatin are relatively small as compared with the number of structural and physiological characteristics of an organism; so that we may not assign to each of these bodies the exclusive responsibility of reproducing a given adult character. The present idea is rather that each chromosome is a complex body, varying in shape (Fig. 205), which contains a varying number of "determiners" (hypothetical bodies) which have the potential power under appropriate conditions of causing the developing cells to take on a given form. This does not mean that the chromosome or the germ cell is a miniature adult that simply unfolds, but rather that the initial or determining cause is in the germ cell and that the full expression of characters comes through a continuous series of developmental stages which is determined by the condition of the determiners in the fertilized egg cell.

The cells of the body are divided into body plasm or soma and the germ plasm. Weismann restricted the germ plasm to the nucleus of germ cells, but the term is coming now to refer to the whole of the germ cell. In this more liberal use of the term germ plasm the determiners are not exclusively confined to the chromatin but are found in all parts of the germ cells. After the germ plasm has given rise to an individual, a portion of it is left behind, which participates in the formation of new offspring, and as Davenport phrases it, "there really is no inheritance from parent to child, but parent and child resemble each other because they are derived from the same germ plasm, they are chips from the same old black; and the son is the half-brother to his father, by another mother."

In any such study one should always keep in mind the fact that the chromosomes grow and increase in volume just as the other parts of the cell grow. Were it not for this growth in the chromosomes, it would be inconceivable how such a small amount of substance could produce such definite results. This relation is emphasized by the estimate of Parker who states that the human chromosomes in the ovum weigh about 0.000004 milligram. This makes the weight of the hereditary determining material to the average weight of a man as 1 to 16,250,000,000,000.

Mendelism.—The Augustine monk, Gregor Johann Mendel, published, in 1865, the results of his studies on the pedigree culture of peas, in which he announced an important theory of heredity.

This theory points out two important facts: (1) That the parental characters may reappear in the offspring as unit characters; and (2) that one character usually is so prominent that it completely obscures or prevents the other from appearing. It is said to dominate the weaker character. These two ideas are readily observed in Figs. 205 and 206. Here a white and black guinea-pig are crossed and the first generation is all black. These offspring are called the hybrid generation and the black color completely dominates over the white. The white color is not lost, as the subsequent breeding

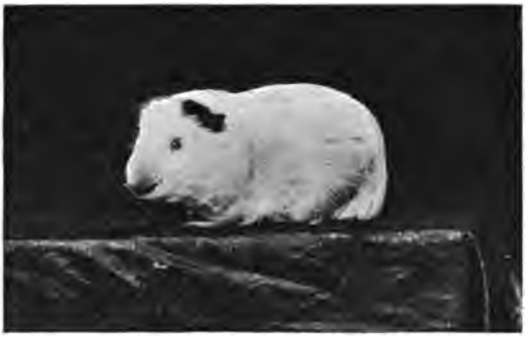


Fig. 205.—An albino male guinea-pig, father of the black young shown in Fig. 206 (After Castle.)

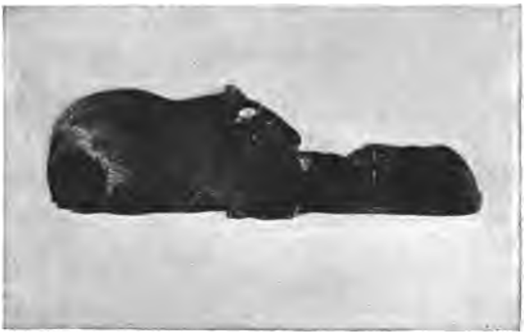


Fig. 206.—A female guinea-pig and her young sired by the albino in Fig. 205. (After Castle.)

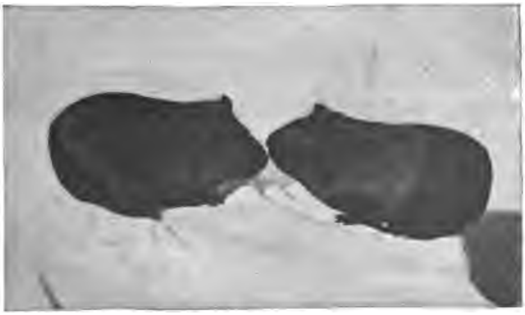
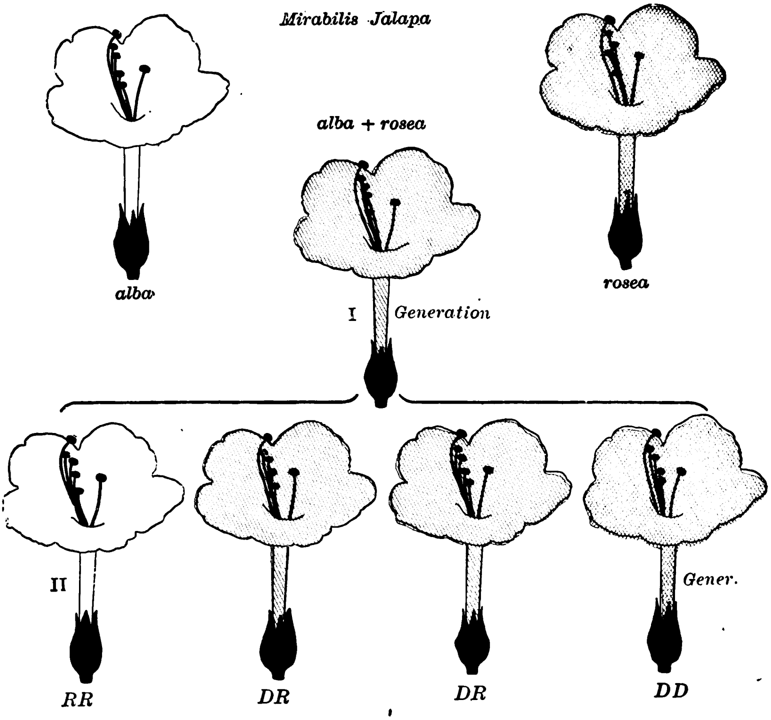


Fig. 207.—Two of the grown-up young of the litter shown in Fig. 206.

PLATE VII


Mirabilis Jalapa
alba
alba + rosea
rosea
I *Generation*
II
Gener.
RR
DR
DR
DD

experiments prove. Now as these hybrid black guinea-pigs are allowed to interbreed, definite results follow which are illustrated in Fig. 208. Three of the second generation of hybrids are black and

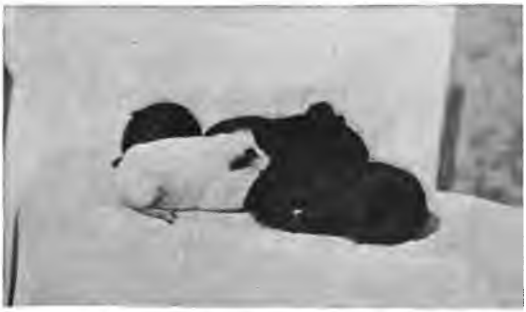


FIG. 208.—A group of four young produced by the pair in Fig. 208. Note the reappearance of the white in a one-fourth ratio.

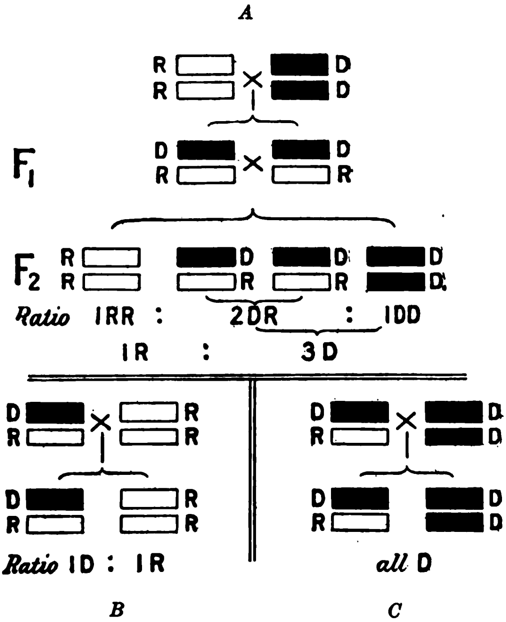


FIG. 209.—Schema of Mendel's law for a single pair of "antagonistic" properties. *A*, the results of hybridization of a pure dominant (*D*) with a pure recessive (*R*) form; *B*, the results of crossing a hybrid with a recessive form: 50 per cent. of progeny pure recessive, 50 per cent. hybrid (but apparently dominant); *C*, the result of crossing a hybrid with a dominant form; all apparently dominant (but 50 per cent. pure, 50 hybrid). (Bateson.)

one is white. As both of the parents are black, the white color must have existed in the germ plasm, although the parents gave no evidence of being partly white. Specific terms are used to describe these facts of heredity. The black color is said to be dominant over the white; and the white color is recessive to the black. Black and white are unit characters. The second generalization is a theoretical inference drawn from the dominant and recessive relationships of such unit characters as black and white. In order that the white color shall reappear in the second hybrid generation, the hereditary

Fig. 210

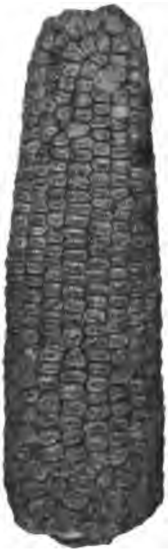


Fig. 211

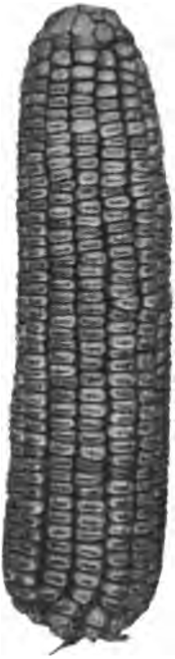
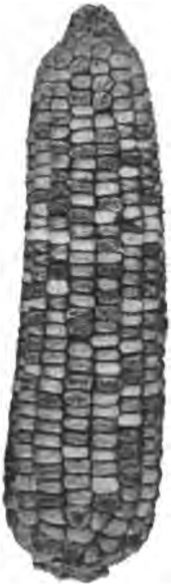


Fig. 212

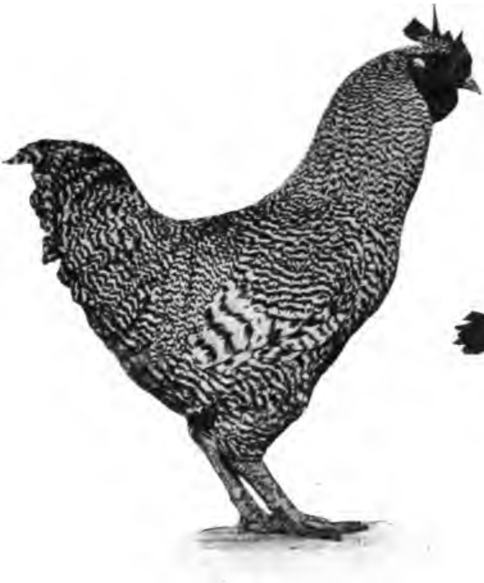


Figs. 210, 211 and 212.—Showing Mendelian inheritance in maize. Fig. 210, pure sweet parent race; Fig. 211, pure dent parent race; Fig. 213, ear bearing F_2 progeny kernels from the cross of Figs. 210 with 211. The ears bearing F_1 progeny kernels are indistinguishable in appearance from the pure dent parent ears (Fig. 211). In general it may be said, the F_1 kernels resemble most closely the dent parent in their chemical characters. In other words, there is a definite tendency toward the complete dominance of the chemical conditions found in the dent parent over those found in the sweet parent. This dominance is by no means perfect in all characters, however. In particular, the F_1 kernels are plainly intermediate between the two parents in respect to sugar content. The F_1 kernels in these experiments are not to be told by visual examination from the pure dent parent, yet a chemical analysis shows that they really are different. (Pearl and Bartlett.)

determiner for white must have been present in the first generation of black hybrids and remained uninfluenced by its association with the hereditary determiner for black. This is known as the purity of the germ cells, which means that the determiners for both black and white do not occur in all the germ cells. The white guinea-pigs of the second hybrid generation when crossed with white guinea-pigs will give rise to white guinea-pigs only. The same result follows with part of the black, while some of the black continue to give offspring that are white and black. This latter condition is diagrammatically shown in Fig. 209, and the reason that there is one white to three black is explained. Pure dominants and pure recessives result when both the sperm and ovum contain black determiners and white determiners respectively. There are other important results which recent students of heredity have discovered and other theories than Mendelism which are fully discussed in the references at the close of this chapter. Mendelism has been reviewed in this chapter in preference to other theories because at present it seems to explain a larger proportion of facts.

The unit characters which are now generally recognized have in some cases a general distribution in the organism. "Tall and dwarf habits are diffuse characters of the plant as a whole. Hairiness may be on stem, leaves, calyx, part or all of them. Mendelian hereditary units are not leaves, petioles, stamens, etc., but qualities of these organs or still more diffuse qualities of the whole plant." (Harper). In the same sense human stature, temperamental vigor, or resistance to disease are unit characters that are inherited and are qualities which are a part of the whole body. Heredity is to be looked on as determining the character of the cells, as those in the skin or muscles; and as formulating the qualities of the organism as a whole; for example, it is a dog with all of the dog characteristics.

According to the cytologists, heredity means the normal combination of the chromosomes, although some are willing to admit that the rest of the cell may play an important part. The more deeply one studies into the problem, the more difficult it becomes to formulate a definite hypothesis. The recognition that characters behave as units in heredity has served to add a new avenue of study, with the result that breeders in particular are able to select more successfully than ever before the characters that they wish to emphasize. But the whole story is not so simple, for some of the unit characters are associated in pairs, as it were, and some of the characters, like skin color, for example, are now known to depend upon a number of determiners.



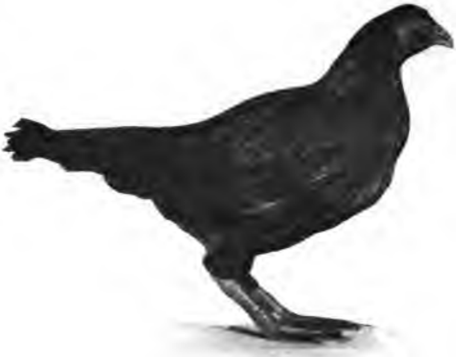
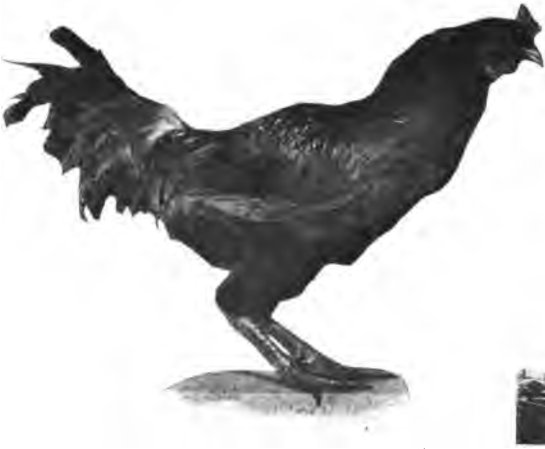


FIG. 213.—Pure bred barred Plymouth Rock. ♂.

FIG. 214.—Pure bred Cornish Indian game. ♀.

If one mates the cross-barred Plymouth Rocks ♂ × Cornish Indian game ♀ he gets only barred birds. (Pearl and Surface.)



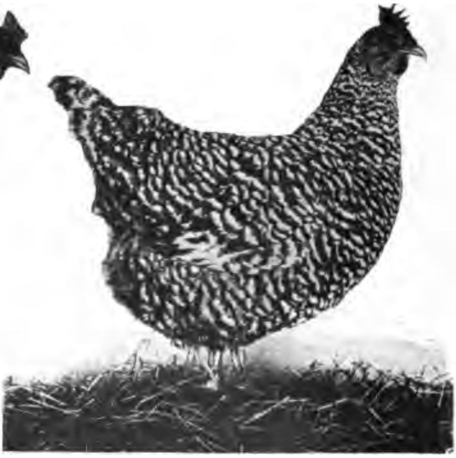


FIG. 215.—Pure bred Cornish Indian game. ♂.

FIG. 216.—Pure bred barred Plymouth Rock. ♀.

If one mates Cornish Indian game ♂ × barred Plymouth Rock, all the male offspring will be barred and the female will be black. (Pearl and Surface.)

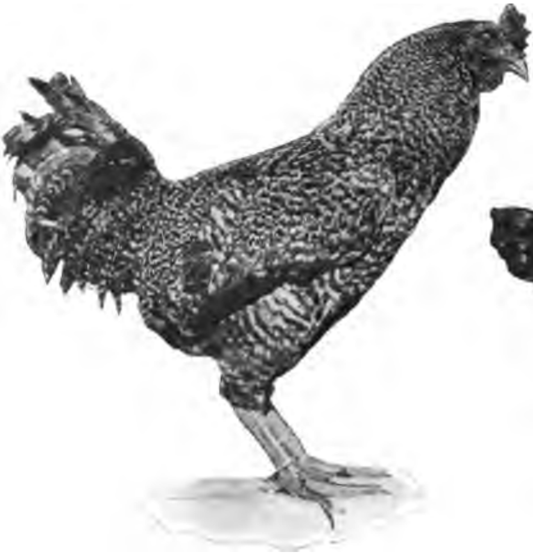


Fig. 217.—Barred F_1 hybrid ♂.

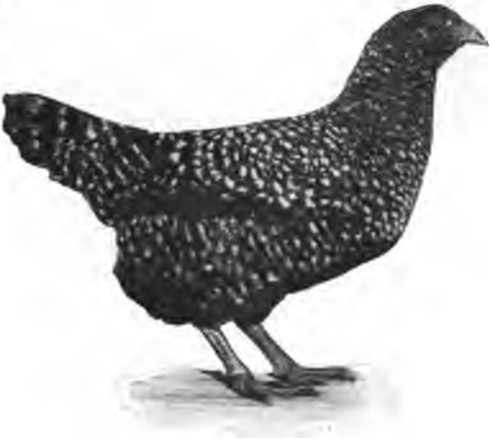


Fig. 218.—Barred F_1 hybrid ♀.

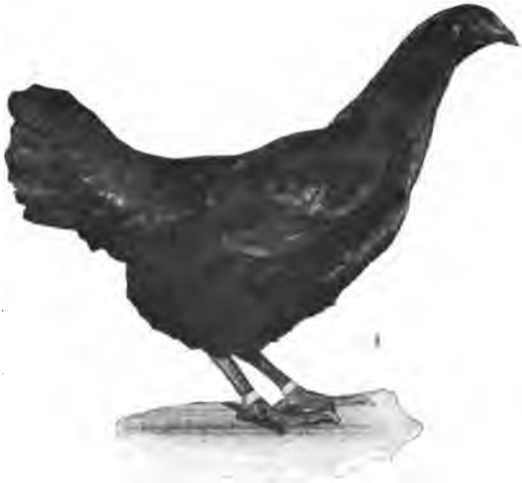


Fig. 219.—Non-barred (solid black) F_1 hybrid. ♀.

Figs. 213 to 219 show that barring of the feathers is inherited in a sex-limited fashion. The barred pattern is inherited as a unit character and there is no evidence of a blended inheritance of degrees of intensity of pigmentation. No more striking evidence of the segregation and particulate behavior of characters as units in inheritance can be found anywhere. (Pearl and Surface.)

"There are, however, instances in which it appears that Mendelian segregation may not be perfect. It has been maintained that an instance of this is provided by hair-length in guinea-pigs. When a long-haired ('Angora') guinea-pig is mated with a short-haired, the F_1 offspring are short-haired; shortness being dominant, owing perhaps to the presence of a factor which prevents the growth of the hair after reaching a certain length. But when such F_1 (heterozygous) short-hairs were mated together, in addition to apparently pure longs and shorts, animals with hair of intermediate length were produced, and these crossed back with pure long-hairs gave no short-haired young. It is suggested that the long and short characters have become fused in some germ cells, segregation being incomplete or non-existent, so that germ cells bearing the mixed character are produced. Again, in a cross between lop-eared and short-eared rabbits, young with ears of intermediate length are produced, and these mated together give no evidence of segregation in the next generation. From these and some other similar observations it must be concluded, either that in some cases there is incomplete segregation or even complete fusion of alternative characters, or that what appear to be simple characters are really complex, and that the true-breeding intermediates are formed by a new combination of elementary factors." (Doncaster.)

An illustration of the practical value of what may seem to some an academic discussion is seen in the testing out of the theory of unit characters as follows: "Some valuable wheats are liable to the attacks of a fungus giving rise to the disease called 'rust,' other less valuable races are immune. Biffen has found that by crossing the two races together, fertilizing the hybrids (F_1) among themselves, and selecting the homozygous plants in the F_2 generation, wheat can be produced which combines the valuable features of one race with the immunity to rust of the other, and so a new and most useful variety of wheat is produced."

The tendency at present is to fix the attention upon some character and observe its behavior in heredity. Francis Galton first recognized that there is a tendency for certain characters of the parents to blend in the offspring while others are alternative. When the brown-coated, lop-eared rabbit is crossed with an albino, short-eared angora rabbit, the offspring has ears of intermediate size, which sometimes stand erect and sometimes lop. The hair of the offspring in the above cross was short and black, the long white hair did not appear; but where these black hybrids were bred, the parental characters reappeared in their offspring in a definite proportion.

"The effect of crossing a pigmented rabbit with an albino is similar to that produced when two pieces of glass, one transparent, the other opaque, are held up together. We see only the opaque one. Never-

Fig. 220

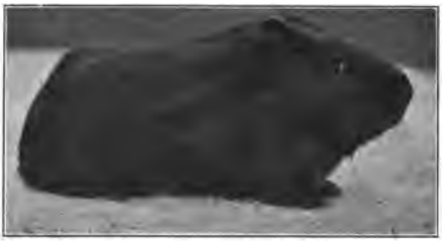


Fig. 221

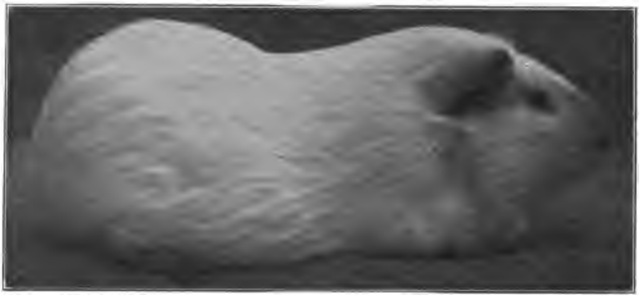
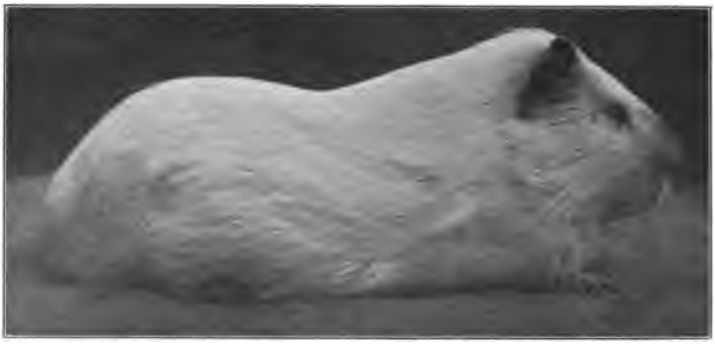


Fig. 222



Figs. 220, 221 and 222.—Fig. 220, a young black guinea-pig, about three weeks old. Ovaries taken from an animal like this were transplanted into the albino shown in Fig. 221. Fig. 221, an albino female guinea-pig. Its ovaries were removed and in their place were introduced ovaries from a black guinea-pig (Fig. 220). Fig. 222, an albino male guinea-pig, which was mated with the albino shown in Fig. 220. (Description and figures from W. E. Castle.)

theless, the two conditions have not blended; each retains its original distinctness, and the two can be separated again at will. So it is in the Belgian produced by cross-breeding with an albino. The albino character is there, though unseen, and will appear as a distinct entity when the cross-breed reproduces, for it will be represented in

Fig. 223

Fig. 224

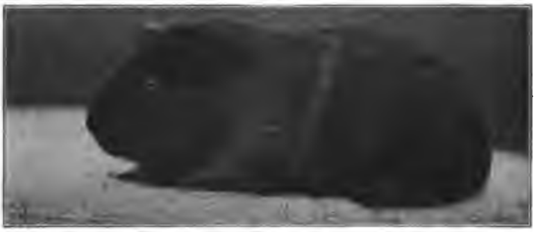
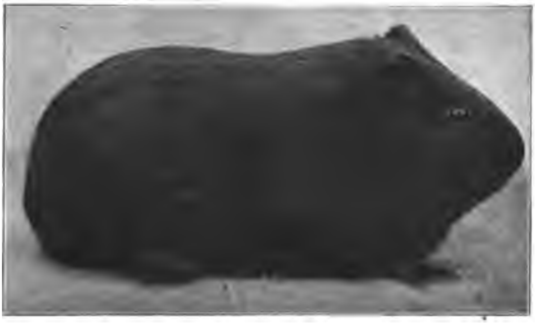


Fig. 225



Figs. 223, 224 and 225 are pictures of three living guinea-pigs, all of which were produced by the pair of albinos in Figs. 221 and 222. From evidence such as this it is concluded that the inheritance cannot be affected by modifications of the body of the parent, not even when the body is completely changed, since the body so far as heredity is concerned is merely a container of the reproductive cells. To modify the inheritance we must modify the reproductive cells. (Description and figures from W. E. Castle.)

approximately half of the sex cells formed by the cross-bred animals, the alternative or Belgian character being represented in the other half. It is as if the two pieces of glass, combined originally to illustrate the formation of a cross-bred animal, were separated again to illustrate the formation of the reproductive elements by the cross-bred. For every element formed having the opaque character there will be another having the transparent character, but there will be no elements of an intermediate nature." (Castle.)

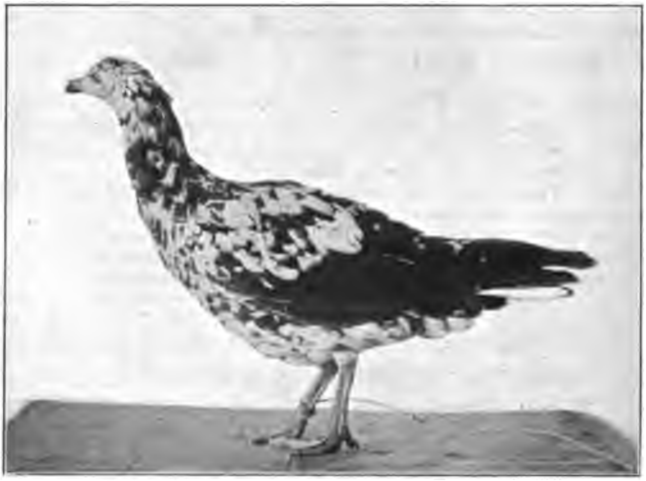


FIG. 226.—Hybrid fowl which is a cross between guinea hen and game-cock, showing in an interesting manner the distinctive color of both parents. This is a form of mosaic inheritance. (Bred and photographed by Dr. Raymond Pearl.)

For the discussion of latency, atavism, acquired characters, prepotency, origin of sex, and other equally important and interesting phases of heredity, the student is referred to the many elaborate works on heredity.

Heredity and Man.—No statement can be made about the laws of heredity in plants and animals that is not in a general sense applicable to man. It remains to be shown that all forms of inheritance follow the unit character law, which is being advocated by some of the present writers. At any rate it serves to clarify greatly the whole subject of inheritance. A great deal of attention is being given to the study of pedigrees of man and to noting in what proportion defects for example are handed on from generation to generation.

The Kallikak Family.—The story of this family has been traced from the present back to Revolutionary days. The first Martin

Kallikak (name fictitious) was of good English ancestry, but he took advantage of a feeble-minded girl, with the result that she had a feeble-minded son. From this son there have been 480 descendants with the following history: 36 were illegitimate, 33 sexually immoral, 24 confirmed alcoholics, and 3 epileptics. Over 80 died in infancy, 8 kept houses of ill-fame and 143 were feeble-minded. Forty-six of the 480 were found to be apparently normal.

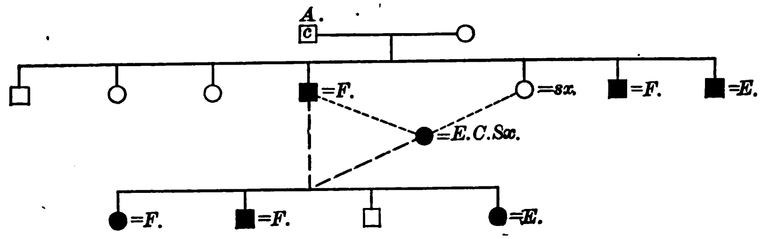


FIG. 227.—This chart illustrates the hovel source of defectives. A feeble-minded man had by his defective sister an epileptic daughter with criminal instincts; then by this daughter he had four children, two feeble-minded, one epileptic, and the fourth an anencephalic monster who died directly after birth. The empty germ plasm yields only emptiness. These things were done in a little hut in the woods until it burned down and now mother and eldest daughter, when not in the county jail or the Monmouth County Almshouse, live in a cellar in town. The man is dead, but some of his protoplasm is living and at large. (Case 3165.—Davenport and Weeks.) *A.* = alcoholic; *c*, criminal; *E.*, epileptic; *F.*, feeble-minded; *Sx.*, unchaste.

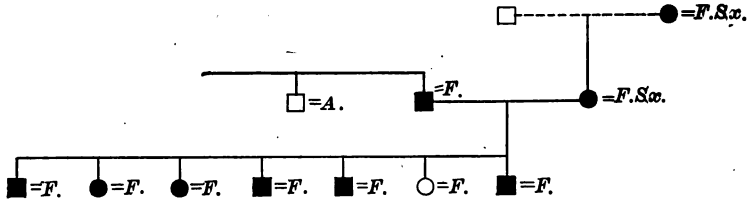


FIG. 228.—This chart illustrates again the product of two feeble-minded parents. The father belongs to a fair strain except that his brother also is alcoholic. The mother, like her mother in turn, is immoral. There are seven children, of whom six are known. One of these is an epileptic at State Village and all of the others are feeble-minded. After the father's death the mother had an illegitimate child who died in infancy, and she is now married to a feeble-minded and alcoholic man who is the younger brother of her daughter's feeble-minded husband. (Case 3031.—Davenport and Weeks.)

The man who started this long line of delinquents married a Quaker girl after the Revolutionary War and from this legal union 496 descendants have been traced. There is no trace of feeble-

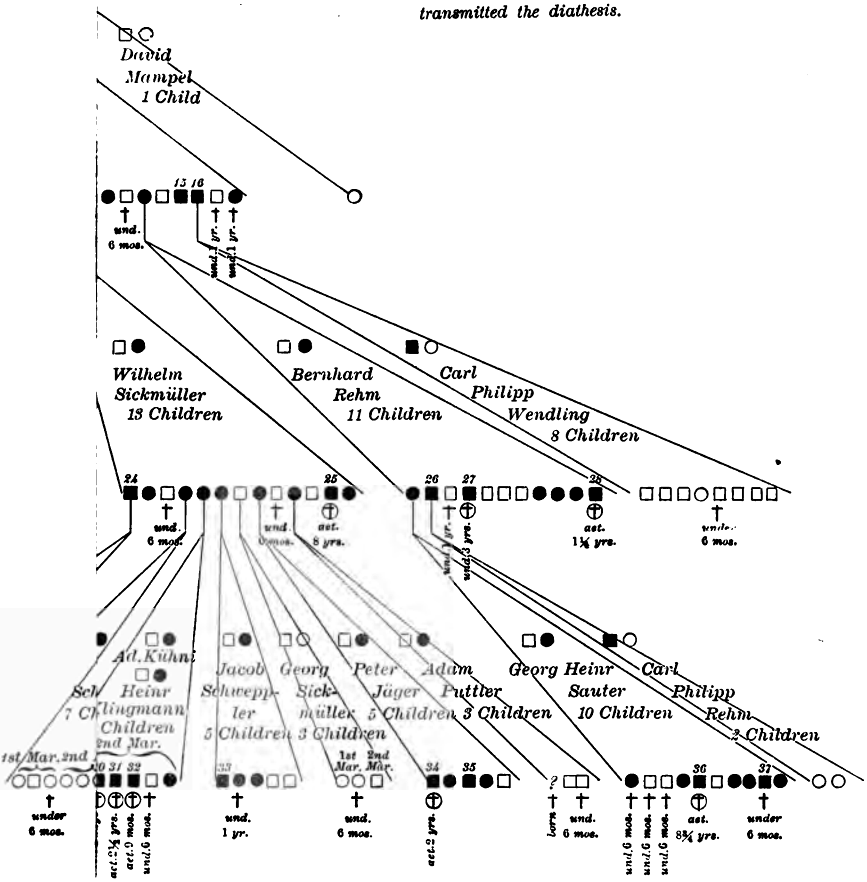
GENE

MA
OF

Co

(Deutsch. Z

□ *Male without Hæmophilia.*
○ *Female without Hæmophilia and without diathesis.*
■ *Bleeder (Male).*
● *Daughter of a Bleeder family.*
⊕ *Died from Hemorrhage.*
The Males of the family alone have been Bleeders but have not transmitted the hæmophilic diathesis. The Females have never been hæmophilic but have transmitted the diathesis.



mindedness and but 2 cases of insanity. None of the offspring has been criminal or ne'er-do-well.

The descendants of the same father and the normal and the defective mother have been studied, as they lived in the city and country and the same marked discrepancy obtains. In the cities the legal descendants are lawyers, physicians, and respectable business men; while the others live in the slums. The same phraseology describes the differences between the two in the rural districts. Wealthy and influential farmers employ unknowingly their distant relatives who are shiftless and subsist by the aid of charity. ("The Kallikak Family," Goddard.)

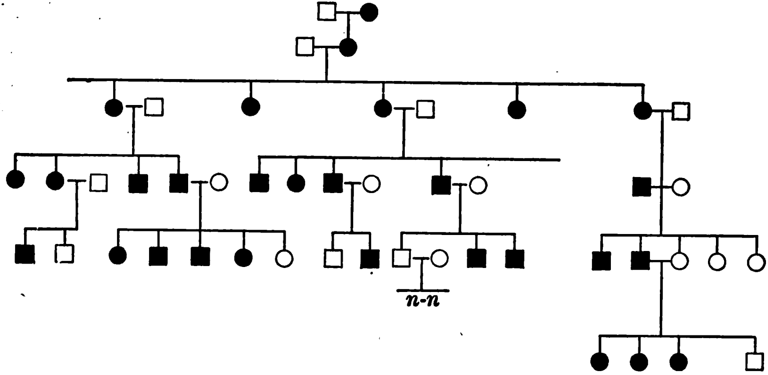


Fig. 229.—Pedigree of a family with poorly nourished nails and hair, the black symbols. (Nicolle et Halipre, from Davenport.)

Eugenics.—Eugenics is the term which describes the application of the laws of heredity to man, especially emphasizing the beneficial results of good mating. It has served to direct attention to the inheritance of defects as well as musical skill or scholarly interests. The results are summed up in Davenport's book on *Heredity in Relation to Eugenics.*

Much remains to be discovered concerning the exact method of heredity and the causes of variation, although sufficient is known to enable us to understand more clearly their relation to evolution and their importance to mankind. Variation and heredity are two terms used to describe kindred characteristics of living protoplasm which are always present where life exists. They are as fundamental as metabolism and like it understood only in part. Heredity and variation are not opposing characters, but according to several writers variation is an expression of incomplete inheritance.

REFERENCES.

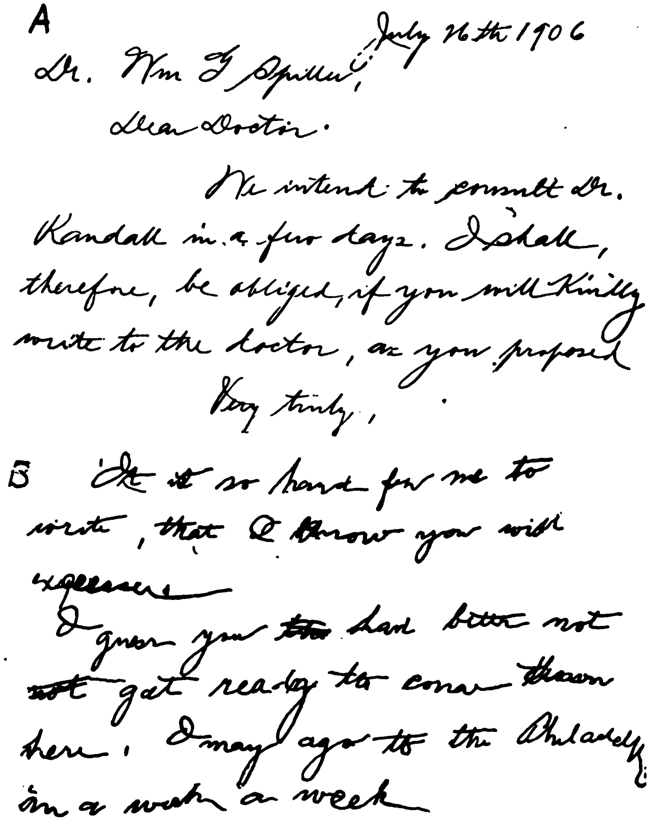
Bateson, W.: Mendel's Principles of Heredity.
Castle, W. E.: Heredity.
Castle, Coulter, Davenport, East Lawar: Heredity and Eugenics.
Darbishire, A. B.: Breeding and the Mendelian Discovery.
Lillie, Frank R.: History of the Fertilization Problem, Science, January 4, 1916, p. 39.
Morgan, T. H.: Heredity and Sex.
Punnett, R. C.: Mendelism.
Reid, G. A.: The Laws of Heredity.
Thompson, I. A.: Heredity.
Wood, F. A.: Heredity and Royalty.

CHAPTER XXIV.

ANIMAL BEHAVIOR AND ITS RELATION TO MIND.

An important phase of biology is the general problem of animal behavior and the development of intelligence. As we have endeavored to emphasize, evolution implies genetic relationship. It is a very strange procedure that utilizes the theory of evolution to explain the development of the muscles, skin, skeleton, nervous system, etc., of animals and omits animal behavior. Just at present it seems best to use this rather ill-defined term *animal behavior* rather than mind for the varied expression of mentality among animals, because there is some difference of opinion as to the use of the word mind, and the term animal behavior enables us to approach the topic without prejudice. The substance, then, of this chapter deals with material that we may regard as on the border-line between experimental psychology and animal behavior. This is a field of investigation in which zoölogists have been very active and in which they have made most of the contributions. Until the limits of this field become more clearly defined, it may properly be included under biology.

We know sensations directly only in ourselves. Each individual is isolated from all other individuals and the nervous system of one gives out no material substance to another, therefore we are compelled to judge of the sensations of others by our own feelings or states. At the very outset of our consideration of animal behavior we are beset with our greatest difficulty, namely, how to judge and interpret the actions of animals, especially the simpler ones. We stand at one side and look on without being able to enter fully into their lives. We can never know directly how an animal feels or how an object looks to him. When we see an animal apparently in pain, we say that if we were acting that way, it would be because we were in pain, therefore the animal must be suffering. The possibility of wrong interpretation of this point is made clearer by the two following experiments: Take the common earthworm and cut it in two about in the middle. The posterior part writhes and twists, doubling itself up into various knots. The first time we see this to speak and had difficulty in walking. This time the dura was cut and a tumor was located and removed. Recovery was complete. The most interesting feature of this case is shown in Figs. 231 and 232, which give specimens of the patient's handwriting. The second case is that of a woman, aged thirty-two years, who in childhood had received a blow on the left parietal region from a croquet mallet. The family noticed a gradual development of certain abnormal mental states and sought medical advice. When asked if she saw anything unusual, she answered "Yes; holes in the ceiling and walls; small ones; many of them." There was no defect in the ceiling, nor was it papered. There was nothing to be mistaken for holes; in other


A
July 26th 1906
Dr. Wm G Spiller,
Dear Doctor.
We intend to consult Dr.
Randall in a few days. I shall,
therefore, be obliged, if you will kindly
write to the doctor, as you proposed
Very truly,

B It it so hard for me to
write, that I know you will
excuse
I guess you ~~the~~ had better not
~~not~~ get ready to come then
here. I may ago to the Philadelp
in a week a week

FIG. 230.—*A*, writing nineteen days after the first operation. The man could not write at all for some time before the operation; *B*, writing fourteen days before the second operation. (Spiller.)

words, this was a true hallucination, not an illusion. While the pupillary reactions were being looked for, she volunteered the information that her eyes had been operated upon a short time before and when asked if anything else had been done, she replied, "Yes, my right leg was cut off recently." A tumor was removed from the hip-shoulder-elbow area of the brain as shown in Fig. 232 and the patient recovered.[1]

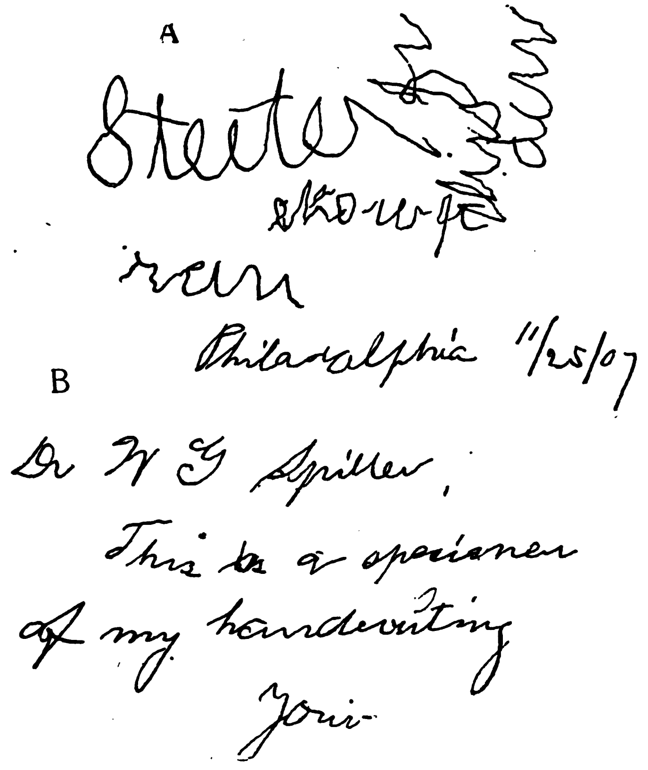

A
B
Philadelphia 11/25/07
Dr W G Spiller,
This is a specimen
of my handwriting
Your

FIG. 231.—*A*, writing done with the left hand three or four days after the second operation, the right hand could not be used in writing; *B*, writing on the eighth day after second operation. (Spiller.)

The influence of the body on the mind is further shown in the facts of inheritance. As has already been outlined, it is seen that feeble-mindedness and some forms of insanity are inherited. In this connection the normal facts of growth should not be forgotten.

---

[1] The first case is by Dr. W. G. Spiller, in Am. Med. Jour., December 21, 1907, xlix, 2059. The second is from Drs. Langdon and Kramer, ibid., December 3, 1910, lv, 1960. Here the full details of each are given.

For the mental life of the child, the youth, the adult, and the aged are all well-recognized stages and reveal a very intimate relation between the mind and body.

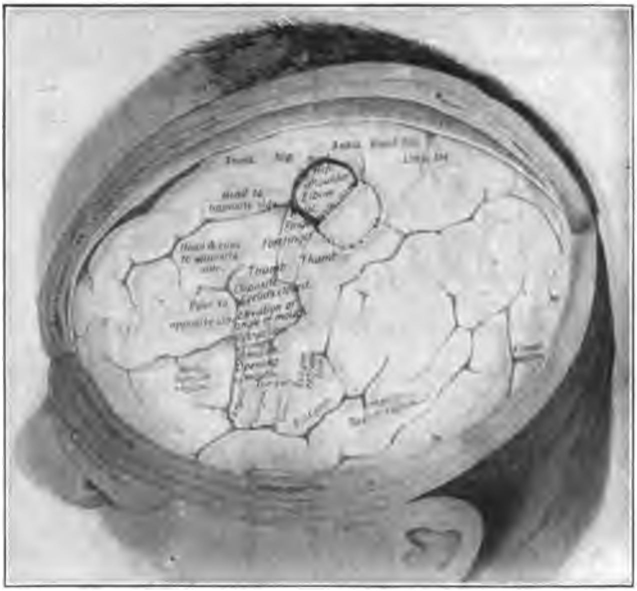


FIG. 232.—Location of brain tumor. (Langdon and Kramer.)

Sense Organs.—Animals become aware of their environment and the varied changes in it through their sense organs. In the simple protozoa, the whole external surface acts like a generalized sense organ in being able to receive and conduct such stimuli as fall upon it. It is impossible to state just how many kinds of sensation an animal may experience, but it is probable that he has many more than the five kinds usually thought of in the popular mind, *i. e.*, sight, hearing, touch, taste, and smell. "Some kinds of animals have few senses, some have many. Some are strikingly like man in sensibility, others are as strikingly different. The dog, like the human being, has a sense of smell, but it is extremely different from the human sense in degree of development. Indeed, so acute is olfactory sensibility in this animal that psychologists have thus far found no way to study it. The dog's sense of sight also is markedly different from man's, for it apparently does not include color vision. Certain animals, like the lobster and the crab, lack hearing. They are sensitive to slight jars and vibrations in the surface upon which they rest, but they utterly lack what we understand by sensations of sound. On the other hand, there is excellent reason to believe that there are animals in which senses exist of which we have no knowledge. How else are we to explain to ourselves the remarkable ability of certain beings to find their way home or to make long migratory journeys? We must not permit ourselves the thought that all animals experience the same sensations, or even that they possess the same modes of sense." (Yerkes.)

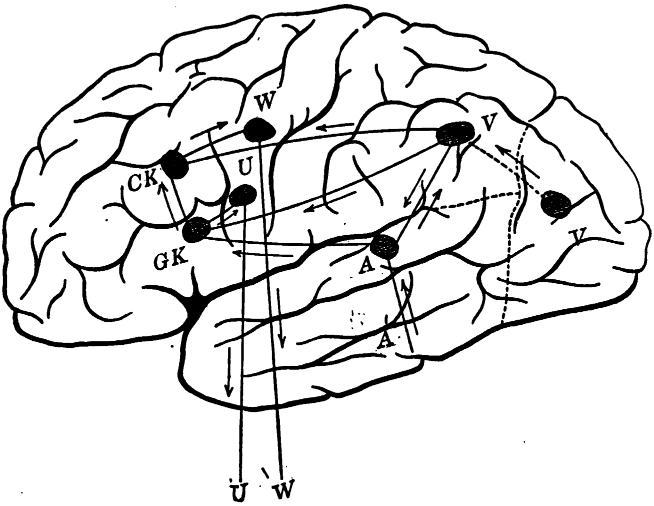


FIG. 233.—Diagram showing probable pathways of nervous impulses concerned in speech and writing. In right-handed persons these centers and tracts are situated in the left side of the brain; in left-handed persons the opposite is the case. *A*, centre for auditory word memories in first temporal convolution; *V*, center for visual word memories in angular gyrus; *GK*, glossokinesthetic center (Bastian), or psychomotor center, at foot of third convolution; *U*, centers for muscles involved in articulation at foot of ascending frontal convolution; *CK*, probable centers for memory of muscular movements involved in writing, cheirokinesthetic center of Bastian; *W*, centers for controlling muscles of arm and hand in ascending frontal convolution; *A–A′*, tract from cortex of temporal lobe (auditory centers) to center for word memories; *V–V′*, tract from cuneus to center for visual memories; *W–W′*, tract from arm and hand centers to cells in anterior horns of cord and peripheral nerves controlling these muscles (pyramidal tract); *U–U′*, tract from centers for muscles of articulation to centers in pons and medulla and nerves controlling those muscles (pyramidal tract). In speaking, impulses travel from *A–GK–U–U′;* in reading aloud, from *V–A–GK–U–U′;* in silent reading, from *V–A–GK;* in writing spontaneously, *V–A–GK–CK–W–W′;* in writing from dictation, *A–V–GK–CK–W–W′;* in copying, *V–CK–W–W′*. (*N*, naming center; *S*, stereognostic center in parietal lobe.) (Potts.)

The world that we live in, and the same is true for animals, is determined by the presence of sense organs and the efficiency with which they serve us. The following lines were read to a blind student:

> "His words were shed softer than leaves from the pine,
> And they fell on Sir Launfal as snow on the brine,
> That mingle their softness and quiet in one
> With the shaggy unrest they float down upon."

He was then asked to tell what sort of a picture he had. He could form none because he had never seen the pine leaves falling; similarly, the deaf person lives in a silent world. While the sense organs or their equivalents are the main sources of information concerning the world, yet it is extremely difficult to imagine how the several stimuli in its environment affect the protoplasm of an ameba. If it were not for the fact that man can tell us how he feels, thinks, etc., we would have to judge of his mental condition by his actions or, what we denominate in the case of animals as behavior. "Anthropomorphism signifies unjustifiable reading into lower organisms the characteristics, particularly the mental ones, that we find in ourselves, and especially it signifies substituting these for causal explanation. This is a serious error. But it has nothing to do with another question with which it is often confused. This other question is, whether the behavior of animals resembles in any features the behavior of man. This is purely a question of observed fact, not one for prejudice or for *a priori* consideration of any sort. The only way to answer it is to learn the objective facts for man and for animals, and then to compare them, observing where there are resemblances, where differences. Some of these are: the fact that reactions are due to the release of internal energy; that action may occur without specific stimulus; that action is modified by internal changes of the most varied character, many of which are parallel in man and protozoan; that negative reactions are given mainly to injurious agents, positive ones to beneficial agents; that varied reactions occur under the influence of a single constant stimulus, and that the organism tends to persist in that reaction which keeps it in condition favorable to its life processes." (Jennings.)

SOME TYPES OF ANIMAL BEHAVIOR.

The following facts illustrate some of the phases of animal behavior. They are such facts as any student can collect himself after becoming trained in making critical observations of this nature. The responses which animals make, as thus shown in these quotations, are capable of more than one interpretation. The student should consult the texts suggested at the close of this chapter for assistance in his analysis.

Ameba.—When an ameba is moving about and enters a brightly illuminated area, in nearly all instances it stops. "The details in the response which resulted in the change in direction of motion and thus kept the organism out of the intense light were essentially the same in all of the specimens observed. They are graphically recorded for a single individual in Fig. 234. By referring to this figure it will be seen that after one pseudopod came in contact with the illumination and was stopped, the ameba did not at once proceed in the opposite direction so as to avoid the light, but sent out other pseudopods at only a slight angle with the first, apparently trying to get around the obstacle in this way. The character of the response did not change after the first pseudopod came in contact with the light, nor did it change after the second and third came in contact with it. But after the fourth became exposed the direction of motion

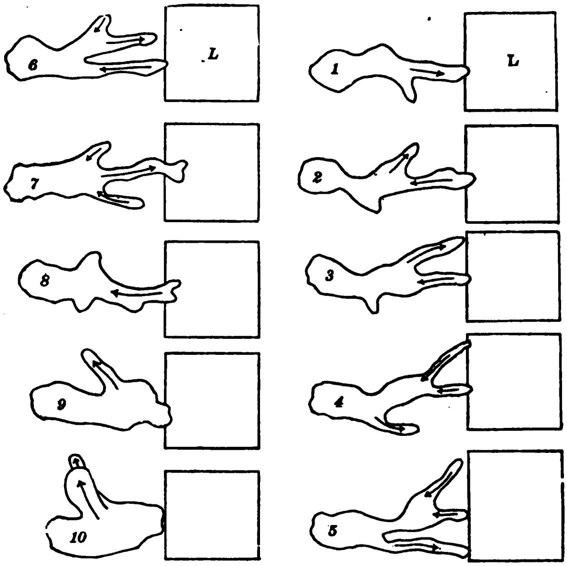


FIG. 234.—Sketches representing the reactions of an ameba proceeding toward an intense area of light, the rays of which were perpendicular to the slide. *L*, field of light formed by focussing a limited section of a Welsbach mantle on the slide. 1 to 10, successive positions of an ameba a little less than one-half minute apart. Arrows indicate direction of streaming pseudopods. (From Mast, Jour. Exper. Zoöl.)

was nearly reversed. This indicates that the reaction was modified, that the response to a given stimulus depends upon preceding experience." (Mast.)

Gonionemus.—This is a medusa with four radial canals from which gonads are suspended. The tentacles vary in number from 30 to 80. The manubrium is a short stalk hanging from the under surface. "An experimental study of the reactions of Gonionemus to chemical stimuli was begun by observation of the manner in which normal animals react to fish-meat. A small piece of fresh fish placed upon the tentacles causes a reaction which usually presents five fairly well-marked phases: (1) Those tentacles that have been touched by the meat contract, twisting about one another in such fashion as to hold the food and carry it along with them; (2) the group of contracting tentacles bend in toward the mouth; (3) that portion of the margin of the bell bearing the contracting tentacles contracts, thus drawing the tentacles nearer to the manubrium; (4) the manubrium bends over toward the side from which the food is brought, until finally the lips touch the food; and (5) the meat adhering to the lips is slowly surrounded by the manubrium."

"The tentacles of normal Gonionemata react to nearly all stimuli by a contraction which simply shortens the organs, but to some foods and to motile touch-stimuli they frequently react by twisting into the form of a corkscrew in contracting. It may now be asked, Are these reactions of the tentacles dependent upon the central nervous system? This question finds its answer in the results of experiments upon isolated tentacles. Tentacles were cut from the bell about a millimeter from their attachment and placed in Stender dishes containing sea-water. For a few minutes after excision they usually remained in a contracted condition; then expanded and became very active and sensitive to stimuli. Gelatin or meat applied to them called forth the corkscrew contraction. To other stimuli they respond with the usual straight contraction. It is therefore evident that the tentacle contains within itself the mechanism necessary for these reactions, and is not dependent upon the functional activity of the entire organism, nor upon the central nervous system for its ability to execute them." (Yerkes.)

Earthworms.—Yerkes designed a T-shaped labyrinth of plate glass, with runways 2 centimeters wide, which was used to test the ability of earthworms (*Allolobophora fetida*) to "learn" to follow a simple path and to avoid an injurious chemical (or electrical) stimulus by reacting negatively to a peculiar tactile stimulus which regularly preceded the chemical. He had in mind these two questions: (1) Can the worm profit by experience; (2) can it "associate" the tactual stimulus with the chemical and acquire the habit of regularly responding to the sandpaper as though it anticipated the effect of the salt? From October 12, 1911, to April 30, 1912, a single worm was given 850 trials in passing through the labyrinth under various conditions. The results showed that the worm was capable of acquiring certain modes of reaction which involve a definite direction of movement and the association of two stimuli. He says: "In view of this positive result of training, it was deemed worth while to proceed with the next step in the investigation—namely, amputation of the anterior segments, with the 'brain,' in order that the relation of the habit to the 'brain' might be studied. Forty hours after the operation it seemed desirable to resume the experimentation. With the apparatus arranged precisely as in the previous series of trials, the worm was permitted to enter the T. It moved forward, more slowly and continuously than before the operation, into the middle of the stem. Having reached the common wall of the arms it turned to the left and five times pushed forward to the sandpaper, each time withdrawing upon contact.

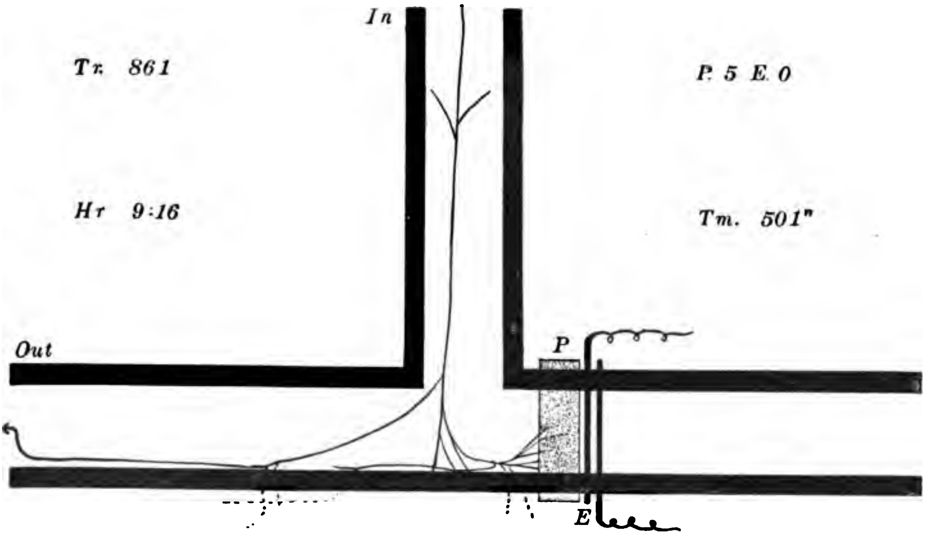


FIG. 235.—Diagram of T. showing path followed by earthworm in first trial after removal of the brain. *E*, pieces of copper wire serving as electrodes, insulated and kept at a fixed distance from one another by rubber; *P*, strips of sandpaper. (Yerkes.)

As it searched with the cut end, for a way of escape, the 'tail,' became active and moved about as if 'feeling' for a path. Shortly a turn toward the right was made and, with repeated attempts to crawl up the glass wall, the worm approached the exit tube. The instant the 'head' end came in contact with the moist lining of the tube the worm pushed forward as in 'recognition' of the retreat (Fig. 235)."

"The correct performance of a thoroughly ingrained habitual act of the kind studied in this investigation is not dependent upon the 'brain' (portions of the nervous system carried by the five anterior segments), since the worm reacts appropriately within a few hours after its removal. As the brain regenerates, the worm exhibits increased initiative, its behavior becomes less automatic, more variable. Two months after the removal of the 'brain,' during the last four weeks of which period no training was given, the habits had completely disappeared. Systematic training of two weeks resulted in the partial reacquisition of the original direction habit. The various facts recorded in this investigation indicate that the removal and the regeneration of the first five segments resulted in the development of a worm strikingly different in behavior from the original worm." (Yerkes.)

Wasp.—One of the solitary wasps (*Ammophilia*) stores its nests with caterpillars which it paralyzes by stinging the ventral ganglia. "In the three captures that came under our observation, all the caterpillars being of the same species and almost exactly of the same size, three different methods were employed. In the first seven stings were given at the extremities, the middle segments being left untouched, and no malaxation was practised. In the second seven stings again, but given in the anterior and middle segments, followed by slight malaxation. In the third only one sting was given, but the malaxation was prolonged and severe. Of 15 caterpillars some lived only three days, others a little longer, while still others showed signs of life at the end of two weeks. There is not a single species in which the sting is given with invariable accuracy. To judge from results they scarcely sting twice alike, since the victims of the same wasp may be killed at once or live from one day to six weeks, or perhaps ultimately recover." (Peckhams.)

Habit Formation in Frogs.—"July 29, I placed 30 of the hairy caterpillars in the cage. *Rana sylvatica* attempted to eat a caterpillar seven different times within an hour but rejected it each time. Following these trials no other caterpillars were visibly reacted to. By attempting to eat a caterpillar and then rejecting it is meant this: The frog shot out the tongue in the normal manner, bringing the caterpillar back to the mouth, then extruding the tongue slowly, slightly wriggling it. In most cases this muscular wriggling freed the caterpillar from the tongue; if it did not, the withdrawal of the tongue into the mouth scraped off the caterpillar in nearly every case." On August 9, 12.30 P.M. "The caterpillar was placed in the cage again, *Rana sylvatica* reacted first by making two short hops to orient so as to look directly at the caterpillar. (The caterpillar was about 5 cm. in front of the frog.) The head of the frog was then slowly lowered and brought forward toward the caterpillar, but I could not see that the tongue was shot out, although I watched especially to see if this would happen. In a second or two the head lurched forward a little more and then the tongue was very slowly extended, barely touching the caterpillar. The tongue was now withdrawn and then suddenly extruded, with what appeared as a very slight attempt to shake the caterpillar off. The caterpillar elicited no further response during the next forty-five minutes." (Schaeffer.) For four days the frogs were scantily fed and then a caterpillar was put in the cage. *Rana sylvatica* took no notice of it. *Rana sylvatica* formed the habit of avoiding hairy caterpillars in seven trials.

Raccoons.—"The animals all succeeded in learning to work seven fastenings: namely, two buttons, two bolts, lifted by a pull on each of two loops hung in different parts of a large box, one thumb latch, one bolt raised by the animal's mounting a platform and a horizontal hook placed at the left side of the door. In boxes of two to seven fastenings there is almost no tendency to follow a routine order in undoing them. The average time required for the first success after being put through is very much less than the average time for the first success by trial and error." (Cole.)

Significance of Animal Behavior.—The question naturally arises, In what way is animal behavior related to the mind of man? The several illustrations cited in the preceding section indicate that there is no hard-and-fast way in which an animal reacts to a stimulus, such as a too bright light in the case of the ameba or the manner of undoing the fastenings of a box in the case of the raccoon. It is also very difficult to make a classification such as reflex, instinct, habit and say that the behavior of the animals already referred to falls into these usual classes. The behavior of animals passes imperceptibly from one stage into another. The number of cases selected has to be limited but when many more are added to the ones given the gradation is more apparent. In short it is difficult to mark limits even to instinct which is usually thought of as acting in an exact and perfect manner. Can one feel sure that the wasp is acting instinctively after reading Peckham's account? The quotations in the preceding section permit one to use Yerkes' very suggestive plan in attempting to explain the history of the development of mind. The rest of this section is taken from his account in his *Introduction to Psychology.*

The Psychology of One-celled Organisms.—In the opinion of the authorities who have given this matter most careful consideration the mind of the one-celled animals consists of a certain limited number of sense qualities, together with feelings of agreeableness and disagreeableness. The sense qualities are not necessarily the same in all of the animals of the group; on the contrary, there probably are considerable variations. There is no sufficient reason for assuming that the animals experience ideas, memories, emotions, sentiments, thoughts, or any of the psychic complexes which have been observed in man. Their mental lives are extremely, delightfully simple as compared with ours. Theirs must be lives of simple awareness of certain features of their surroundings, without even the consciousness of self as distinguished from environment. There is absolutely no reason for supposing that they are self-conscious. In a word, the organisms of this our first group are psychologically below the level of the infant newly born.

The Psychology of Simple Multicellular Animals.—Here sensations exist in a much greater variety of mode and quality than is the case in the mind of the one-celled animals. Feelings exist, too, and apparently in more complex forms than in simpler organisms. Certain evidences of images, lacking perhaps the elements of recognition or the feeling of familiarity, are discoverable, and we must conclude that the minds of these creatures resemble that of the infant at birth more closely than do those of simpler creatures. Many varieties of worms and crustaceans and coelenterates are known to profit by experience in ways which strongly suggest consciousness of the representative sort. But we must not be overgenerous in our ascription of mental states to them.

The Psychology of the Insect Group.—Ants, bees, wasps, and other social insects evidently experience a great variety of sense qualities. There are evidences that their feelings also are vivid and varied. The effective side of their experience consists predominantly of instinct consciousness. This fact, coupled with the observation that a larger number of their environmental relations are definite and almost automatically met in action, has led to the impression that they lack complex experiences and are mere creatures of instinct. It is high time that biology and psychology took account of the fact that instinct as a form of action has as its accompaniment an important effective variety of consciousness.

It is difficult to place the animals of this group in their relation to the history of consciousness in the race. They seem to lie off the direct line of progress and they may well be considered a divergent group. To compare them directly in their mental life with human beings is even more difficult, for in some respects they are more remarkable than the two-year-old child, while in others they are hopelessly inferior. With reason, one might claim that certain of the insects are psychologically superior to man and represent a stage in the evolution of mind which, although strikingly different, is more advanced than our own. And, on the other hand, it must be admitted that the direction in which our mental life has developed is not to be conceived of as a stage in the evolution of insect consciousness. Rather we may conclude that the social insects represent the highest development of mind in one direction; and man, the highest development in another direction. It is not for us with modesty to insist that our psychic characteristics are best.

The Psychology of the Lower Vertebrate Animals.—The fishes, frogs, salamanders, and toads are far less interesting psychologically than many of the insects. They possess many modes of sense and a fair degree of discriminative ability, but of complex rational experiences, emotions, sentiments, associations, memories, they apparently have few or none. If the mind of man is to be conceived of as having evolved from that of the frog or a fish, a vast gap must be bridged, for there is a world of difference in mental make-up.

The reptiles and birds have a wider range of experiences and, in some instances, they appear to live a life of emotions and memories. Many of them appear to be on the level of the higher insects, although markedly different from them in respect to complexity of instinctive behavior. Rationality of a sort may be attributed to some of them. It is different from ours, doubtless, in that there is less clear and inclusive awareness of the conditions and results of action. Between the most intelligent representatives of this large group of vertebrates and man there is a gap which ages of development might have bridged.

The Psychology of the Higher Vertebrates.—With this group we reach those animals to which we feel mentally most akin. For in the horse, the dog, the raccoon, the squirrel, and others of the mammals we discover experiences like our own. This is not simply because many of these animals are our hearthside companions and patient servants. Even in the creatures of the wild we detect many similar mental traits. For all of the animals of this group, save those toward which we have some special cause for enmity, we have a degree of sympathy and interest which far surpasses that which we feel for the other animals about us. Therefore it is that we object to the abuse or mutilation of a dog, although we may quite calmly eat a live oyster or plunge a living lobster into hot water.

There is no question, in the mind of the person who really knows animals, that the higher vertebrates possess a great variety of sense qualities and feelings. Doubtless these differ in many respects from ours, and even among one another, but on the whole they appear to be more nearly like ours than those in any other group of living things. Of emotions, sentiments, associations, memory images, ideas, and even certain forms of judgment there are more worthy evidences, and the more liberal among psychologists are at present inclined to believe that at least some animals, among them the dog and horse, the raccoon and cat, experience conscious complexes which are much like ours. It is upon this subject that the attention of animal psychologists, who are interested in what animals feel rather than merely in what they do, is now concentrated.

The Psychology of the Primates.—To be sure the primates are higher vertebrates and also mammals, but by their closer resemblance structurally to us as well as by their mental traits, they are entitled to be placed in a separate class. It is not alone in bodily form that they are strikingly like us. They share a large portion of those psychological peculiarities which distinguish us from animals. The monkeys and apes are man-like in their curiosity, their emotional life, their ideas, their memories. Between the other vertebrates and the highest apes there is a great psychological gulf. It is almost as difficult for the imagination to bridge it as it is to imagine the transition from the mental life of the fishes to that of the bird.

For the intimate and thorough student of the animal mind it is by no means difficult to think of the mind of the monkey or the ape as a step in the evolution of the human mind. The difference in mental life is a matter of degree, not of kind. Few traits which man possesses seem wholly lacking in the other primates.

SOME VALUABLE REFERENCES ON ANIMAL BEHAVIOR.

COLE: Intelligence of Raccoons, Jour. Comp. Neur. and Psych., 1907, xvii, 211.

L. EDINGER: The Relations of Comparative Anatomy to Comparative Psychology, Jour. Comp. Neur. and Psych., 1908, vol. xviii.

HOLMES: The Evolution of Animal Intelligence.

JENNINGS: Behavior of Lower Organisms.

LOEB: Comparative Physiology of the Brain.

LUBBOCK: On the Senses, Instincts, and Intelligence of Animals.

SCHAEFFER: Habit Formation in Frogs, Jour. Animal Behavior, 1911, i, No. 5.

SHERRINGTON: The Integrative Action of the Nervous System.

THORNDIKE: Animal Intelligence.

WASHBURN: The Animal Mind.

YERKES: The Dancing Mouse.

YERKES: Introduction to Psychology.

YERKES: The Intelligence of Earthworms, Jour. Animal Behavior, 1912, ii, No. 5.

APPENDIX.

CLASSIFICATION OF ANIMALS AND PLANTS.

Animal Kingdom.—The following general plan of classifying the animal kingdom is taken from Parker and Haswell, and serves to show how animals are grouped, but does not determine the exact relation of even the great phyla.

I. Phylum Protozoa, 8000[1] species living.
  Classes 1. Rhizopoda: ameba.
    2. Mycetozoa.
    3. Mastigophora: spirochetes, trypanosomes.
    4. Sporozoa: gregarines, all parasitic.
    5. Infusoria:
      Class Ciliata.
      Order, Holotrichida.
      Family, Paramedicæ.
      Genera, Paramecium.
      Species: Paramecium caudatum, Paramecium aurelia.
II. Phyllum Porifera, 2500 species.
  Class Porifera; sponges.
III. Phylum Cœlenterata: 4500 species.
  Classes 1. Hydrozoa: hydra, sea-anemone, jelly-fish.
      Hydrariæ.
      Hydra viridis.
      Hydra fusca.
    2. Scyphozoa: jelly-fish.
    3. Actinozoa: corals.
    4. Ctenophora.
IV. Phylum Platyhelminthes: 5000 species.
  Classes 1. Turbellaria: flatworms.
    2. Trematoda: liver fluke.
    3. Cestoda: tapeworms.

---

[1] The estimate of the number of species in each phylum is by H. S. Pratt.

V. Phylum Nemathelminthes, 1500 species.
  - Classes 1. Nematoda: ascaria, trichina, uncinaria.
  - 2. Acanthocephala: hook-headed worms, echinorhynchus.
  - 3. Chætognatha.

VI. Phylum Trochelminthes, 500 species.
  - Classes 1. Rotifera.
  - 2. Dinophilea.
  - 3. Gastrotricha.

VII. Phylum Molluscoida, 1700 species.
  - Classes 1. Polyzoa.
  - 2. Phoronida.
  - 3. Brachiopoda.

VIII. Phylum Echinodermata, 4000 species.
  - Classes 1. Asteroidea: star-fish.
  - 2. Ophiuroidea: brittle stars.
  - 3. Echinoidea: sea-urchins.
  - 4. Holothuroidea: sea-cucumbers.
  - 5. Crinoidea: crinoids.

IX. Phylum Annulata, 4000 pecies.
  - Classes 1. Chætopoda: earthworms.
    - Oligochaerta.
    - Lumbricidæ.
    - Lumbricus terrestris: Common earthworm.
  - 2. Gephyrea.
  - 3. Hirudinea: leeches.

X. Phylum Arthropoda, 394,000[1] species.
  - Classes 1. Crustacea: Crabs, lobsters, etc.
    - Macrura.
    - Astacidæ.
    - Astacus Cambarus: Common cray-fish.
  - 2. Onychophora.
  - 3. Myriapoda: centipedes.
  - 4. Insects.
    - 1. Order Aptera: spring-tails, snow-fleas.
    - 2. Order Ephemeridæ: May-flies.
    - 3. Order Odonata: dragon-flies, damsel-flies.
    - 4. Order Plecoptera: stone-flies.
    - 5. Order Isoptera: white ants.
    - 6. Order Corrodentia: book-lice, bark-lice.

---

[1] Some authorities estimate that the insects alone number 600,000.

7. Order Mallophaga: biting bird-lice.
8. Order Thysanoptera: thrips.
9. Order Euplexoptera: earwigs.
10. Order Orthoptera: cockroaches, grasshoppers.
11. Order Hemiptera: bugs, head-louse.
12. Order Neuroptera: ant-lion, dobson-fly.
13. Order Mecoptera: scorpion-flies.
14. Order Trichoptera: caddis-flies.
15. Order Lipidoptera: butterflies, moths.
16. Order Diptera: flies.
17. Order Siphonaptera: fleas.
18. Order Coleoptera: beetles, potato-bug.
19. Order Hymenoptera: bees, ants, wasps.
    Apidæ.
    Apis mellifica. Honey bee.

XI. Phylum Mollusca, 61,000 species.
    Classes 1. Pelecypoda: clams, oysters.
        Unionidæ.
        Anontoides.
        Anodonta fluviatiles.
    2. Amphineura.
    3. Gastropoda: snails.
    4. Cephalopoda: squid, devil-fish.

XII. Phylum Chordata.
    Subphylum 1. Adelochorda.
    2. Urochorda: tunicate, 1300 species.
    3. Vertebrata.
        Acrania: amphioxus.
        Craniate.
            Classes 1. Cyclostomata: lemprey.
            2. Pisces: fishes, 13,000 species.
            3. Amphibia: 1400 species.
                Urodela: salamanders.
                    Anura: frogs and toads.
                    Salienta.
                    Ranidæ.
                    Rana pipiens.
                    Rana catesbiana.
                    Rana clamitans.

4. Reptilia: horned toad, lizard snake, turtle, alligator, 3500 species.
5. Aves: birds, 13,000 species.
6. Mammalia: dog, cat, sheep, seal, rabbit, monkey, man, etc., 3500 species.

The Plant Kingdom.—Largely from Bergen and Caldwell.

Phylum I. Thallophyta.
  Subphylum I. Myxomycetes: slime moulds, sometimes classed as animals.
  Subphylum II. Schizophyta. 2020 species.
    Class I. Schizomycetes: bacteria.
    Class II. Schizophyceæ: blue-green algæ.
  Subphylum III. Algæ.
    Class I. Chlorophyceæ; the green algæ. 8950 species.
    Class II. Phæophyceæ: the brown algæ. 1030 species.
    Class III. Rhodophyceæ: the red algæ. 3050 species.
  Subphylum IV. Fungi. 64,400 species.
    Class I. Phycomycetes: moulds and mildews.
    Class II. Ascomycetes: mildews, cup-fungi, etc.
    Class III. Lichens.
    Class IV. Basidiomycetes: mushrooms, rusts, etc.
Phylum II. Bryophyta.
    Class I. Hepaticæ: liverworts. 4000 species.
    Class II. Musci: mosses. 12,600 species.
Phylum III. Pteridophyta.
    Class I. Filicineæ: true ferns. 3800 species.
    Class II. Equisetinæ: scouring rushes or horse-tails. 24 species.
    Class III. Lycopodineæ: club mosses or ground pines. 700 species.
Phylum IV. Spermatophyta.
  Subphylum I. Gymnosperms. 540 species.
      Order. Coniferales: pine, spruce, firs, etc.
  Subphylum II. Angiosperms.
      Order I. Monocotyledons: corn, grasses, lilies, etc. 23,700 species.
      Order II. Dicotyledons: hardwood trees, roses, etc. 108,800 species.

INDEX.

A

Abiogenesis, 114
Absorption, 40
Achromatic, 57
Adaptation, 198
Adrenal body, 30
  tumor, 226
Afferent nerve, 66, 172
Alternation of generations, 133, 145, 157, 208
Amanita, 216
Amino-acid, 39
Amitosis, 95, 106
Amphibia, 20
Amylopsin, 39
Anaërobic, 107
Anaphase, 76
Animal behavior, 281
  pole, 70, 80
Anopheles, 221
Anther, 136
Antheridium, 129
Antibodies, 234
Antitoxins, 232
Aphis, 208
Arteries, 42, 242
Arthropoda, 177
Ascaris, 225, 265
Astacus, 177
Astral fibers, 75
Auricle, 43
Autrotrophic, 99
Axon, 64

B

Bacillus, 108
Bacteria, 43, 46, 85, 91, 108–113, 176, 218
Bat skeleton, 24
Bed-bug, 199
Bees, 189–197, 211
Bile, 39
  duct, 29
Biogenesis, 114, 146, 148, 241
Blood, 43–44
Branchiobdella, 210
Bulbus arteriosus, 43
Butyrin, 37

C

Calcium, 116
Calyx, 136
Capillary, 45, 65
Carbohydrate, 37, 100
Carbon, 116, 140
  dioxide, 46, 101, 164
Cardiac valve, 26
Cartilage, 54
Catalytic agent, 40
Cell, 55, 57, 65, 68, 121, 241
Cellulose, 97, 106, 110
Chitin, 178, 187
Chlorine, 116
Chlorophyle, 99, 126, 133, 149
Chloroplast, 97, 126, 164
Choroid plexus, 58, 60, 91
Chromatin, 57, 71, 73, 98, 264
Chromatophores, 126
Chromosomes, 75, 145, 264, 266, 267
Cilia, 86, 90, 110
Cleavage, 80
Clinostomum, 200
Clitellum, 168
Cloaca, 26, 27, 31
Cnidocil, 156
Coccus, 108
Cœlom, 33, 167, 173
Cœnocyte, 127
Colony, honey bee, 188
Conductivity, 66, 93, 123
Connective tissue, 53–54
Coördination, 66, 94, 123
Corolla, 136
Corpora adiposa, 33
Corpuscles, 43
Crayfish, 177–186
Cuticle, 170
Cytoplasm, 57, 86, 98, 110, 126

D

Darwin, 252
Dendrite, 62
Deutoplasm, 70
Digestion, 38
Digestive glands, 27
    liver, 27

Digestive glands, pancreas, 29
Dicotyledons, 135
Disaccharids, 37
Dissepiments, 167
Dominant character, 270

E

EARTHWORM, 166–172
Ecdysis, 178
Ectoderm, 154, 169
Ectoplasm, 86
Efferent nerve, 66, 172
Embryology, 34, 68–84
Endoderm, 154, 169
Endoplasm, 86
Endopodite, 176
Endosperm, 145
Endospore, 111
Enzyme, 38, 92, 102, 107, 112, 130, 140, 182
Epithelial tissues, 52–54
Eudendrium, 162
Eustachian tube, 26
Evolution, 34, 239
Excretion, 46, 163
Exopodite, 179
Exoskeleton, 178, 187

F

FATS, 37, 91, 102
Female pronucleus, 77
Ferment, organized, 39
  unorganized, 105
Fermentation, 39, 112
Fertilization, 79, 129, 145, 160, 165
Fibrovascular, 140
Filter, Chamberland, 224
Fish-lice, 205
Fission, 92, 93, 106, 110
Food, 35
Fossil, 248
Frequency polygon, 260
Frog, 19–84

G

GALL-BLADDER, 28
Gametes, 127, 129
Gametophyte, 132, 133
Gastric enzyme, 39
  juice, 38
Germ cells, 68
  layers, 81, 242
  plasm, 264
Glochidium, 203
Glottis, 26
Gonium, 149
Growth, 241

H

HEMOGLOBIN, 43, 152
Heredity, 248, 262–280
Hermaphrodite, 168
Hermit crab, 210
Heterotrophic, 99
Hibernation, 25, 30, 47
Homology, 245–247
Honey bee colony, 188
Hookworm, 225
Hybrid, 268
Hydra, 153–165
Hydrogen, 49, 116
Hyphæ, 130
Hypodermis, 170
Hypostome, 153

I

IMMUNITY, 230
  acquired, 233
Incubation of disease, 223
Insects, 187–197
Irritability, 66, 93, 123, 167
Iron, 116

L

LAMARCK, 250
Lavoisier, 46
Life cycle, 84, 111, 132, 145
Linnæus, 23, 147
Liver, 29, 39, 167
Lungs, 29
Lymph, 54
Lymphatic, 44

M

MACROGAMETOCYTES, 221
Macronucleus, 87, 89
Magnesium, 116
Male pronucleus, 78
Malpighian body, 30
Malta fever, 228
Mantle, 73
Maturation, 73, 265
Megaspore, 143
Mendelism, 267–277
Mesentery, 29, 31
Mesoderm, 169
Mesoglea, 154
Metabolic water, 49
Metabolism, 11, 46, 47, 123, 241
Metamerism, 166, 187
Metamorphosis, 84, 187
Metaphase, 76
Metatrophic, 111

Micrococcus, 108, 228
Microgametocytes, 221
Micron, 108
Micronucleus, 87, 89
Microörganism, 115
Micropyle, 143
Microspores, 141
Mitosis, 74, 104, 110
Mollusca, 173–176
Monocotyledon, 135
Monosaccharid, 37, 101
Morphology, 33
Movement, 17, 66, 90, 93
Müller, 212
Muscular tissue, 54
Mycelium, 131

N

Nematocysts, 154, 156
Nephridia, 168, 182
Neuron, 62, 172, 282
Nitrogen, 116
Nucellus, 143
Nucleus, 57, 97, 106, 265
    endosperm, 145
    female, 77, 265
    macro-, 89
    male, 78, 265
    micro-, 89
    polar, 144
    segmentation, 79

O

Omatidium, 185
Oöcyte, 264
Oögonium, 129, 264
Oösphere, 129
Oöspore, 129
Operculum, 82
Organ, 20
Organism, 18
Ovary, 31, 68, 168
Oviduct, 31, 71, 168
Ovocyte, 69
Ovules, 137
Ovum, 72, 159, 168, 191, 264
Oxidation, 46, 49
Oxygen, 30, 44, 46, 92, 101, 107, 116, 164, 190
Ozone, 46

P

Pancreas, 29, 39
Pancreatic duct, 29
Paramecium, 67, 85–96, 147
Parasites, 125, 133, 200–210
Parasites, facultative, 202
    obligatory, 202
Paratrophic, 111
Parthenogenesis, 192
Pathogenic, 213
Pepsin, 38
Petal, 136
Phagocyte, 43, 167
Phagocytosis, 43
Phlœm, 141
Phosphorus, 116
Photosynthesis, 99–101
Phylum, 146
Physiology, 33
Pistil, 136
Plasma, 44, 91
Plasmodium malaria, 221
    præcox, 222
Pleurococcus, 97–104
Polar cell, 77
Pollen, 137
Pollenization, 144
Polysaccharid, 37
Potassium, 116
Prophase stage, 75
Proteins, 36, 102, 161
    conjugate, 36
    derived, 36
    simple, 36
Protoplasm, 57, 121
Protoplast, 97
Prototrophic, 111
Pyloric valve, 26
Pyrenoid, 127

R

Rana catesbiana, 21–25
    clamitans, 18, 24
    pipiens, 21–25
Ranidæ, 20–21
Rattlesnake, 214
Recapitulation, 245
Recessive character, 270
Reflex action, 67
Regeneration, 160, 170
Respiration, 29–30, 163, 190
Rhizoids, 133
Rhizome, 137
Rudimentary, 32

S

Saccharomycetes, 105
Sacculina, 202
Salminicola, 205
Saphrophytes, 125
Schizomycetes, 108
Schleiden, 56
Schwann, 56

Scientific method, 240
Seals, 211
Secretion, 38, 216
Seed, 135
Segmentation, 79, 160
    nucleus, 79
Seminal receptacles, 168, 191
    vesicles, 168
Sepal, 136
Silicon, 116
Siphon, 175
Sodium, 116
Soma, 267
Somatic cells, 68
Somites, 166, 177
Species, 147
Sperm, 31, 69, 159, 191
Spermary, 31, 68, 168, 183
Spermatocyte, 264
Spermatophyte, 134
Spindle, 74–76
Spiracle, 82
Spirillum, 108
Sporangiophores, 131
Sporangium, 131
Spores, 107, 127, 131, 137
    peridermium, 206
Sporophyte, 132, 133, 145
Sporotrichium, 217
Sporozoit, 222
Starvation, 47
Steapsin, 39
Stearin, 37
Stigma, 137
Sulphur, 116
Symbionts, 125
Symbiosis, 209
Syncytium, 127
Synergids, 144

T

Tadpole, 81–84
Tænia, 201
Teliospores, 208
Telophase stage, 76
Testes. *See* Spermary
Thallus, 125
Tissues, 52–55
Toxic, 232
Toxine, 112, 234
Trachea, 190
Trichocysts, 87, 89
Trypanosomes, 228
Trypsin, 39
Typhlosole, 170

U

Unbone, 173
Unit characters, 270
Uredospores, 208
Ureter, 30, 31
Urinogenital, 30–32
    duct, 32
Uterus, 31

V

Vaccination, 234
Vaccine, 233
Vacuoles, 86–89
    contractile, 87
    food, 89
    gastric, 91
Variation, 256–262
Vas deferens (plus vasa deferentia), 183
Vegetal pole, 70, 81
Veins, 45
Ventricle of brain, 59
    of heart, 43
Vertebrata, 20
Vitelline membrane, 73
Volvox, 150
Vorticellidæ, 149

X

Xylem, 141

Y

Yeast, 105–108

Z

Zoöspore, 128
Zoötoxia, 112
Zygospore, 127, 131
Zymotic, 232
Zymotoxic, 232

LANE MEDICAL LIBRARY

To avoid fine, this book should be returned on or before the date last stamped below.

SEP 26 1919
DEC [illegible] 1920
MAY 26 1921
DEC 17 1921
JUL 5 1922
SEP 29 1922
FEB 22 '23
JAN 12 '26
JUL -7 1927
FEB 20 28
AUG 8 28

46422

D316 Smallwood, W.M.
S63 A text-book of
1918 biology...

NAME	DATE DUE
M. Rothenberg	SEP 22 1919
Drexel	DEC 7 1920
Henry E. Smith	MAY 26 1921
T A Shanley	DEC 17 1921
T A Shanley	JUL 5 1922
Henry E. Smith	SEP 29 1922 MAY DEC '23
Dr Jaffar	JAN 12 '26
Seymour R. Gray	JUL -7 19
Seyhord R. Gray	FEB 2
M. Vermilya	AUG